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Houston Aerosol Characterization Study

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ABSTRACT

An intensive field study of ambient aerosols was conducted in Houston between September 14 and October 14, 1978. Measurements were made at 12 sites using (1) two relocatable monitoring systems instrumented for aerosol and gaseous constituents, (2) a network of high volume air samplers and automated virtual dichotomous samplers, and (3) a network of pilot balloon launch sites for characterizing upper level meteorological conditions. The study produced over 2000 hours of data on ozone, nitrogen oxides, and sulfur dioxide; 1600 hours of aerosol measurements from a condensation nuclei counter, electrical aerosol analyzer, optical particle counter and two integrating nephelometers; 3100 hours of surface meteorological measurements (wind speed and direction, temperature, total solar radiation, ultraviolet solar radiation, dew point, and pressure); and 480 upper air soundings, including 100 with temperature sensors. These data are organized into a computer compatible, uniform data archive for future use. Over 175 total suspended particulate samples, using glass and quartz filters, were collected. The glass filter samples were used to determine mass loadings. Organic analysis was performed on the quartz filter samples by another EPA contractor. Approximately 100 pairs of size-fractionated particulate samples were collected on Teflon® filters, using the dichotomous samplers, for gravimetric and chemical analysis by EPA and/or its contractors. Nine organic vapor samples were collected using Tenax vapor traps, for analysis by another EPA contractor.

The major findings of this study were: (1) Air entering the Houston area from the southeast showed the influence of both background maritime air and anthropogenic sources. During this study, the aerosols in this incoming air consisted mostly of coarse particles (>3 μm in diameter). (2) Aerosols in incoming continental air were predominantly fine (0.1 μm to 3 μm) during both hazy and clear conditions. Particles of this size are of concern because they are easily inhaled into human lungs and because they increase atmospheric light scattering, which reduces visibility. (3) Aerosols from the urban area were predominantly fine (0.1 to 3 μm) and seemed to be of local origin. (4) Aerosols from the industrialized Houston ship channel area consisted of both coarse and fine particles, the latter being of local origin. The above information is summarized below for each of the major area sources.

Typical Fractions of Total Aerosol Volume

	Incoming Maritime Air*	Incoming Continental Air	Urban Core	Ship Channel
Coarse Mode	0.75	0.20-0.30	0.10	0.30-0.75
Accumulation Mode	0.25	0.70-0.80	0.90	0.25-0.70

Approximate Particulate Burden ($\mu g/m^3$)

	Incoming Maritime Air	Pristine Maritime Air	Incoming Continental Air	Urban Core	Ship Channel
Total	80	25	60	100	120
Respirable†	20	No measurements obtained	40-50	90	30-80

(5) Whether good or poor, visibility (as indicated by the light scattering coefficient) seemed to be uniform over the entire area. (6) Visibility consistently improved during the daytime hours at all monitoring sites. (7) The difference in the light scattering coefficients (bsp) measured at ambient temperature and at 25°F above ambient was highly correlated with the ambient relative humidity. This indicates that Houston's aerosols are hygroscopic and that humidity is a major factor influencing local visibility. (8) There was no significant statistical correlation between light scattering coefficient and ozone concentrations. All of these findings are based solely on the data collected during this field study, which are subject to normal experimental errors.

This report was submitted in partial fulfillment of contract No. 68-02-2954 by the Radian Corporation under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period June 13, 1978 to November 9, 1979.

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*May be influenced by anthropogenic sources
†All particles less than about 3 μm

CONTENTS

Disclaimer i
Abstract ii
Figures. vii
Tables xii
Abbreviations and Symbols. xiii
Acknowledgements xv

1. Introduction. 1
2. Summary and Conclusions 3
3. Recommendations 6
4. Experimental Design 10
    Specific Goals 10
    Monitoring Network 10
    Preplanned Experiments 11
    Quality Assurance. 14
5. Experimental Procedures 16
    Relocatable Trailer. 16
    Air Quality Mobile Laboratory. 30
    High Volume and Automated Dichotomous Sampler (ADS) Networks. 33
    Upper Air Monitoring 37
    Quality Assurance Audits 39
    Daily Operations Procedures. 47
6. Results and Discussion. 51
    Data Summary and Inventory 51
    Prevailing Meteorology During the Study Period. 57
    Source Area Characterization 74
    Case Studies 79
    Discussion of Results. 101
7. List of Appendices 117

References 118

Appendix A . .HACS Archival Data Tape Specifications . . . 120

CONTENTS OF VOLUME II

(See Section 7, Volume I for instructions on availability.)

APPENDIX

B Site Descriptions and Photographs of Sites for Monitoring Stations 1
C Experimental Design for Houston Aerosol Study 38
D Meteorological and Gaseous Data Processing Algorithms. 87
E Aerosols Data Processing Algorithms. 94
F Calibration Procedures 96
G ADS Operating Procedures 116
H Radian's Filter Cleaning Procedure 166
I RTI Filter Handling Procedures 181
J Pibal Data Processing Algorithms 190
K Trailer Checklist. 196

CONTENTS OF VOLUME III

(See Section 7, Volume I for instructions on availability.)

APPENDIX

L Data Summary: Trailer 28 Continuous Data. . . . 1
M Data Summary: Trailer 28 Aerosol Data 30
N Data Summary: AQML Continuous Data. 152
O Data Summary: AQML Aerosol Data 165

FIGURES

Number Page

1 Location of the aerosol study sites (Houston Aerosol Characterization Study, 1978). 13

2 R-28 Relocatable trailer (Houston Aerosol Characterization Study, 1978). 17

3 Electrical aerosol sampling chamber (Houston Aerosol Characterization Study, 1978). 22

4 Optical particle counter and microcomputer (Houston Aerosol Characterization Study, 1978) . . . 23

5 Heated and unheated nephelometer sampling system (Houston Aerosol Characterization Study, 1978) . . . 25

6 Example of hourly data summary (Houston Aerosol Characterization Study, 1978). 26

7 Example of aerosol data summary (Houston Aerosol Characterization Study, 1978). 27

8 Aerosol sampling head (Houston Aerosol Characterization Study, 1978) 29

9 Aerosol sampling ports (Houston Aerosol Characterization Study, 1978). 31

10 Air quality mobile laboratory (AQML) (Houston Aerosol Characterization Study, 1978). 32

11 Mounted Beckman samplers (Houston Aerosol Characterization Study, 1978). 35

12 Tenax vapor traps installed on a hivol (Houston Aerosol Characterization Study, 1978). 36

13 Forecast parameter form (Houston Aerosol Characterization Study, 1978). 48

14 Temporal distribution of valid data (Houston Aerosol Characterization Study, 1978). 52

15 Field sampling array for September 23, (Houston Aerosol Characterization Study, 1978). 61

Page

16 Field sampling array for September 26, 27, and 28, (Houston Aerosol Characterization Study, 1978) . . . 62

17 Field sampling array for September 30 and October 2, (Houston Aerosol Characterization Study, 1978) . . . 63

18 Field sampling array for October 3, (Houston Aerosol Characterization Study, 1978). 64

19 Field sampling array for October 4, 5, and 6, (Houston Aerosol Characterization Study, 1978) . . . 65

20 Field sampling array for October 7, 8, and 9, (Houston Aerosol Characterization Study, 1978) . . . 66

21 Diurnal variation of aerosol measurements, site 19, September 18, 1978 (Houston Aerosol Characterization Study, 1978) 81

22 Daily average volume distribution of aerosols, site 19, September 18, 1978 (Houston Aerosol Characterization Study, 1978). 81

23 Volume distribution of aerosols, site 19, September 18, 1978 (Houston Aerosol Characterization Study, 1978). 82

24 Diurnal variation of gaseous constituents, site 19, September 19, 1978 (Houston Aerosol Characterization Study, 1978). 82

25 Diurnal variation of aerosol measurements, site 13, September 27, 1978 (Houston Aerosol Characterization Study, 1978). 84

26 Diurnal variation of aerosol measurements, site 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978). 84

27 Average daily aerosol volume distributions, sites 13 and 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978). 85

28 Aerosol volume distribution, site 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978). 85

29 Diurnal variation of gaseous constitutents, site 13, September 27, 1978 (Houston Aerosol Characterization Study, 1978). 86

Page

30 Diurnal variation of gaseous constituents, site 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978) 86

31 Diurnal variation of aerosol measurements, site 2, October 2, 1978 (Houston Aerosol Characterization Study, 1978) 88

32 Diurnal variation of aerosol measurements, site 23, October 2, 1978 (Houston Aerosol Characterization Study, 1978) 88

33 Daily average aerosol volume distribution, site 2, October 2, 1978 (Houston Aerosol Characterization Study, 1978) 90

34 Aerosol volume distribution, site 23, October 2, 1978 (Houston Aerosol Characterization Study, 1978). 90

35 Diurnal variation of gaseous constituents, site 2, October 2, 1978 (Houston Aerosol Characterization Study, 1978) 91

36 Diurnal variation of gaseous constituents, site 23, October 2, 1978 (Houston Aerosol Characterization Study, 1978) 91

37 Diurnal variation of aerosol measurements, site 17, October 4, 1978 (Houston Aerosol Characterization Study, 1978) 93

38 Aerosol volume distribution, site 17, October 4, 1978 (Houston Aerosol Characterization Study, 1978). 93

39 Diurnal variation of gaseous constituents, site 17, October 4, 1978 (Houston Aerosol Characterization Study, 1978) 94

40 Mobile route for AQML on October 4, 1978 (Houston Aerosol Characterization Study, 1978). 94

41 Sulfur dioxide and carbon monoxide profiles for AQML (Houston Aerosol Characterization Study, 1978) . . . 96

42 Nephelometer and solar radiation profiles for AQML (Houston Aerosol Characterization Study, 1978) . . . 97

Page

43 Ozone profiles for AQML. (Houston Aerosol Characterization Study, 1978) 98

44 Nitric oxide profiles for AQML. (Houston Aerosol Characterization Study, 1978) 99

45 Diurnal variation of aerosol measurements, site 21, October 8, 1978 (Houston Aerosol Characterization Study, 1978) 102

46 Diurnal variation of aerosol measurements, site 22, October 8, 1978 (Houston Aerosol Characterization Study, 1978) 102

47 Diurnal variation of gaseous constituents, site 21, October 8, 1978 (Houston Aerosol Characterization Study, 1978) 103

48 Diurnal variation of gaseous constituents, site 22, October 8, 1978 (Houston Aerosol Characterization Study, 1978) 103

49 Daily average aerosol volume distribution, site 21, October 8, 1978 (Houston Aerosol Characterization Study, 1978) 104

50 Aerosol volume distributions, site 22, October 8, 1978 (Houston Aerosol Characterization Study, 1978) 104

51 Typical Ambient Aerosol Characteristics 106

52 Deposition rates of aerosols in human respiratory tract 107

53 Aerosol volume distributions, site 20, September 27, 1978 (Houston Aerosol Characterization Study, 1978) 110

54 Aerosol volume distributions, site 19, October 3, 1978 (Houston Aerosol Characterization Study, 1978) 110

55 Diurnal variation of light scattering measurements, site 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978) 111

56 Scattergram of light scattering vs. relative humidity. (Houston Aerosol Characterization Study, 1978) 111

Page

57 Diurnal variation of SO_2 measurements, site 19, September 27, 1978 and site 22, October 8, 1978 (Houston Aerosol Characterization Study, 1978) . . . 113

58 Diurnal variation of some primary and secondary pollutants in Pasadena, California on July 25, 1973 114

59 Diurnal variation of gaseous constituents, site 14, October 3, 1978 (Houston Aerosol Characterization Study, 1978) 114

60 Volume distribution of midday Pasadena aerosol on September 3, 1969. 115

61 Correlation between scattering coefficient for visible light and daily maximum ozone concentration observed in New York City, during the NYSAS 1976 115

62 Scattergram of light scattering measurements vs. ozone values (Houston Aerosol Characterization Study, 1978) 116

TABLES

Number Page

1 Monitoring Sites for EPA Houston Air Pollution Study - 1978. 12

2 Audit Results for Station R-28. 40

3 Audit Results for Station AQML. 41

4 Nephelometer Audit Results. 42

5 High Volume Sampler Audit Results 43

6 Meteorological Sensor Audit Results 44

7 Audit Results of EAA in AQML. 45

8 Example of Daily Data Summary for High Volume Samples 50

9 Data Inventory for Trailer R-28 53

10 Data Inventory for AQML Trailer 54

11 Data Summary for the Houston Aerosol Characterization Study (1978) 55

12 Pibal Data Inventory 56

13 Total Suspended Particulate Summary 58

14 Inventory of Automatic Dichotomous Samples Collected for Analysis for EPA 59

15 Inventory of Samples Collected for Organic Vapor Analysis for EPA. 60

16 Peak Daytime Dispersion Classification Scheme . . . 73

17 Peak Daytime Dispersion Conditions, September 15 to October 9, 1978. 73

18 Summary of Aerosol Volume Distributions 105

19 Summary of Particulate Burdens. 105

LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ADS	automatic dichotomous sampler
amb	ambient
avg	average
bsp	light scattering coefficient at ambient conditions
cc	cubic centimeter
cfm	cubic feet per minute
CNC	condensation nuclei counter
DP	dew point
EAA	electrical aerosol analyzer
EPA	U.S. Environmental Protection Agency
GSD	geometric standard deviation
hbs	light scattering coefficient using heated (~25°FΔ) nephelometer
hivol	high volume air sampler
HL&P	Houston Lighting and Power Company
KW	Kilowatt
LBL	Lawrence Berkeley Laboratory
m	meters
mb	millibar
mph	miles per hour
N	wind blowing from the north
NE	wind blowing from the northeast
NNE	wind blowing from the north-northeast
OPC	optical particle counter
P	pressure
pibals	pilot balloons
ppb	part per billion (vol./vol.)
ppm	part per million (vol./vol.)
RH	relative humidity
SRAD	total solar radiation
T	temperature
TACB	Texas Air Control Board
TSP	total suspended particulates
UV	ultraviolet
var	variable
VMD	volume mean diameter
WD	wind direction
WS	wind speed
WSU	Washington State University
XRF	X-ray flourescent analysis

LIST OF ABBREVIATIONS AND SYMBOLS (CONT.)

SYMBOLS

°C	degrees Celsius
°F	degrees Fahrenheit
µg	micrograms
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_3	ozone
SO_2	sulfur dioxide

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INTRODUCTION

The most common perception of poor air quality in the Houston area is the presence of haze. Aerosols, i.e., liquid and/or solid particles suspended in air, cause haze and, in some cases, discoloration of the atmosphere. The purpose of this study was to characterize the aerosols in Houston air and investigate the origin of and factors influencing these aerosols and their effect on local visibility. The concentration of the aerosol particles, considered as a function of particle size, were measured several times an hour throughout the day downwind and upwind of various potential source areas. Visibility and gaseous contaminant concentrations were measured concurrently to determine the relationship (if any) with aerosol measurements. Several meteorological measurements were also made to determine the effect (if any) on aerosol concentrations and visibility. Finally, many samples of aerosols and gases were obtained for chemical analysis by other groups. This aerosol characterization study was one of several sponsored by the U.S. Environmental Protection Agency (EPA) in the fall of 1978 in response to a mandate from Congress to conduct air pollution research along the Gulf Coast. Several reports[1] on this work were presented at a specialty conference organized by the Air Pollution Control Association and held in Houston, October, 1979.

Several preliminary studies of visibility and ambient aerosols have been conducted in the Houston area. Remote sensing and ground-level monitors were used by the University of Texas Health Science Center at Houston to determine aerosol size distribution.[2] In this study, surface reflectance measurements at several wavelengths were obtained photographically using an airplane (9/28/71), a helicopter (9/8/72 and 10/3/72), and a satellite (11/27/72 and 4/27/73). Ground-level size distributions were obtained with a optical particle counter and a cascade impactor. Aerosol samples were obtained with high volume and electrostatic air samplers.

In 1974, The University of Texas at Austin conducted the Houston Urban Plume Study[3] under the sponsorship of the U.S. Environmental Protection Agency. Airborne measurements of SO_2, NO_x, O_3, CO and aerosols were obtained from July 15 through July 24. These data were used to estimate pollutant budgets for SO_2 and NO_x.

In 1975 and 1976, respectively, The Texas Air Control Board conducted two aerosol related projects: Project HASE and the Urban Visibility Assessment (UVA) Study. An integrating nephelometer(s) and a virtual dichotomous sampler(s) were used in Project HASE. Visibility was measured using trained human observers in the UVA project.

The Houston Area Oxidants Study[4] sponsored three aerosol/visibility field measurement programs[5,6,7] in 1977 and a comprehensive data analysis project[8] in 1978. Visibility was measured at several sites in Houston using trained human observers, a telephotometer, and nephelometers. Size-fractionated aerosol samples were also obtained at several sites to determine mass loadings and chemical composition. These field programs obtained data from June through October 1977.

Based on the gravimetric and chemical analysis of size-fractionated particulate samples obtained during this study, R. K. Stevens, et al[1] found that "(1) Houston aerosol is similar in composition and size distribution to aerosols in other major areas in the United States; (2) fine particle mass is generally greater than coarse particles mass; (3) sulfuric acid and/or the ammonium salts of H_2SO_4 are sometimes the most abundant substances in the fine fraction; (4) sulfur concentration decreases when coarse particle chlorine increases; and (5) shale and limestone dominate the coarse particle mass."

Four general source areas contribute aerosols to Houston's air. Air entering the area from the continental land mass to the north may contain aerosols significantly different from aerosols in maritime air coming from the Gulf of Mexico. Similarly, aerosols from industrialized areas, the urban core, and suburban areas may differ significantly. Some particles may be emitted directly to the air, while others may be formed as a result of chemical and/or physical processes occurring in the air. Isolation of a single source area is difficult because of the complex surface and upper level meteorology caused by the interaction of the Gulf of Mexico and the continental land mass.

Due to the many different aerosol source areas and the normal variability in weather, several portable monitoring systems were developed for this study and many monitoring sites prepared. For each wind direction that might occur, several experiments were planned for obtaining data that would allow a characterization and differentiation of various source areas. Each preplanned experiment specified the deployment of the relocatable monitoring systems to the various sites and the samples that should be obtained. At daily planning meetings, the next day's experiments were decided upon, based on special meteorological forecasts and that day's results, and the monitoring systems were then deployed accordingly.

SECTION 2

SUMMARY & CONCLUSIONS

An intensive field study of ambient aerosols was conducted in Houston between September 14 and October 14, 1978. Measurements at 12 sites were made using (1) two relocatable monitoring systems instrumented for aerosol and gaseous pollutants, (2) a network of high volume samplers and automated virtual dichotomous samplers and (3) an upper air system incorporating pilot balloon launches at two locations. Monitoring was conducted to characterize four diverse sources of air impacting Houston air quality; ship channel area, the urban area, incoming maritime air and incoming continental air.

Over 2000 parameter-hours of gaseous pollutant data, 1600 parameter-hours of aerosol data, and over 3100 parameter-hours of meteorological data were obtained. All of these have been assembled into a uniform data archive on magnetic tape for computer use.

Aerosol samples were obtained for gravimetric and chemical analyses using high volume samplers. Organic analyses were performed by EPA-designated contractors on these samples as well as on organic vapor samples. Over 100 pairs of size-fractionated aerosol samples were collected using virtual dichotomous samplers. These samples were analyzed by EPA using XRF techniques and ion chromatography.

The major findings and conclusions from a preliminary analysis of data available to this study follow.

- Incoming maritime air is characterized by a dominant coarse particle (volume) mode. The particulate burden is significantly greater (4×) than measured for pristine maritime air and suggests anthropogenic influence, probably from Texas City and/or Bayport.

- Condensation nuclei and nitric oxide exhibited maxima coinciding with peak traffic periods. This effect was observed to varying degrees at all of the monitoring locations.

- Total aerosol volume and the particle light scattering coefficient (bsp) generally exhibited morning maxima and tended to decrease during the day at all sampling sites used in this study.

- Incoming continental air is characterized by a dominant, aged accumulation (volume) mode, during periods of both good and poor visibility. The air downwind of Houston's urban core is characterized by a dominant accumulation (volume) mode. This aerosol appears to be dynamic (vs. aged) and, as such, probably originates indirectly from emissions in the urban area.

- Houston's ship channel appears to contribute approximately equal amounts of coarse and accumulation mode particle volume. The accumulation mode is dynamic and probably originates indirectly from emissions in the ship channel area. The air downwind of the ship channel may exhibit dominant coarse or accumulation (volume) modes, depending upon the source of the incoming air (maritime or continental, respectively).

- Periods of both poor and good visibility are area wide, with little difference in the particle light scattering coefficient upwind or downwind of major emission areas.

- Increased visibility during the day coincides with a decrease in accumulation mode volume. This observation is consistent for all sources of air.

- No apparent correlation exists between bsp and ozone concentrations.

- A good correlation exists between relative humidity and bsp (ambient) - bsp (heated), suggesting that the visibility in Houston can be significantly affected by volatile water. This fact indicates that Houston aerosols are hygroscopic in nature. Sometimes the bsp (heated) was quite high, indicating poor visibility even under dry conditions.

- Sulfur dioxide was only observed downwind of, or adjacent to, the ship channel. The observed daily concentration profiles for SO_2 were intermittent in nature.

A comparison of the trends and pollutant profiles obtained in Houston with those of other major urban centers show similarities as well as differences. The diurnal variations of gaseous pollutants show no significant difference with the typical patterns observed in other areas. Houston does not, however, show the build-up of aerosol volume and associated visibility reduction at mid-day which is attributed to photochemistry and was exhibited during Los Angeles' smog episodes.

SECTION 3

RECOMMENDATIONS

As a result of this study, numerous areas have been identified where additional research is needed. These generally fall into two groups: (1) Additional analysis of existing data collected in Houston in September and October of 1978, and (2) Additional field studies to provide more information about the formation, composition, and behavior of aerosols.

Specific areas recommended by Radian for additional study include:

1. Additional data analysis should be performed on the data collected in Houston by Radian and other investigators. This should include:

   (a) An air parcel trajectory analysis should be performed on the air mass observed at the upwind station on September 27, 1978 (pp. 77-80). On this day persistent northeast winds brought in air with high ozone and poor visibility at the upwind site. The approximate path of this air mass should be traced to determine where it might have received emissions that would cause the poor visibility and high ozone.

   (b) The chemical analysis results of the fine particulate fraction from the dichotomous samplers at both the upwind and downwind sites should be examined to determine their chemical composition. This may provide clues to the origin of the haze at the upwind site, and to the components added in passing over the ship channel to reach the downwind site.

   (c) The bsp data from the nephelometers frequently indicated an improvement in visibility after mid-morning. This may have been largely due to a decrease in the relative humidity, or to dilution as mixing heights increased. The data on bsp, relative humidity, pilot balloons, temperature sondes, and data from Hobby and Internation airports should be studied to determine the importance of these factors.

(d) The bsp data from the heated nephelometer should be studied in more detail. Regular diurnal patterns, statistical correlations, upwind-downwind differences and other comparisons should be made to determine the behavior and origin of the dried aerosols.

(e) No strong correlation between haze and photochemical activity was noted based on the data collected in this study. Other data should be collected and assessed to determine whether the haze in Houston is strongly influenced by photochemical activity. Included should be data from the HAOS study on ozone, NO_2, PAN, UV solar radiation, visibility (telephotometer), data on gaseous organic compounds collected by EPA in September and October of 1978, and data collected during this period by the Texas Air Control Board on ozone, NO_2, and hydrocarbons.

(f) Data from studies in other cities should be examined to determine whether there is a similar relationship between bsp and relative humidity to that observed in Houston. Candidate cities should include St. Louis, Denver, and Los Angeles.

(g) Additional case studies should be performed on the existing data. Several such studies are described in this report (September 18 and 27, and October 2 and 4). A more detailed description of the meteorology for the case studies is needed to understand the path of the air mass prior to reaching Houston, its movements in the Houston area, and the influence of mixing heights on dilution of the aerosols. Suggested dates for case studies include September 17 and 19 (southwest winds) and October 6 and 7 (northeast winds).

2. The contribution of photochemical activity to the Houston aerosols needs better definition. Several intensive sampling periods should be performed to collect data using dichotomous samplers, nephelometers, ozone monitoring, PAN monitors, aldehyde monitors, nitrogen oxide monitors, and

telephotometers. Meteorological data, including relative humidity, temperature, and solar radiation, should also be obtained to aid interpretation of the data.

3. More detailed meteorological data should be collected during future aerosol studies to better quantify the effect of mixing height, land/sea breezes, long range transport, and local air movements. Numerous public and private groups collect wind speed and direction data, and would make the data available to a scientific study. Upper air data should be obtained using balloons equipped with temperature and pressure transmitters.

4. Additional studies should be performed on the relationship between visibility and relative humidity in Houston. This should include additional work with heated and unheated nephelometers. It might also include an apparatus to artificially increase the humidity without increasing other components.

5. Experiments should be devised to quantify the occurrence of acid mist in the Houston aerosols. This might include the use of a denuder to remove any basic species such as ammonia so that acids collected would not be neutralized prior to analysis. The experiments should measure sulfuric, nitric, and hydrochloric acid.

6. Data are needed on the aerosols in maritime air before they encounter urban areas. The maritime air masses sampled in this study had usually passed over the Texas City area prior to reaching Houston. Data on the physical and chemical composition of the aerosols as they come in from the Gulf are needed to better understand the behavior of Houston aerosols with a maritime air flow.

7. The temporal behavior of Houston aerosols is not well understood. A study should be devised to better define the changes in physical and chemical compositions during a twelve to twenty-four hour period. Such a study might utilize a tetroon as a "marker" for the air mass of interest. An instrumented aircraft could periodically collect and analyze samples near the tetroon. Simultaneously, a mobile station on the ground could collect samples, or a series of dichotomous samplers at fixed locations might be used.

8. Experiments should be devised and conducted to determine the presence of all volatile compounds (e.g., water and organics) that might be normally found on Houston aerosol particles.

SECTION 4

EXPERIMENTAL DESIGN

SPECIFIC GOALS

The overall goal of this study was to obtain evidence on the physical and chemical nature of ambient and ground level aerosols in the Houston area, and on the sources/causes of these aerosols. Highest priority was given to the study of respirable aerosols.

More specific goals of the study included:

- characterization of aerosols and gaseous pollutants downwind of the Houston ship channel,
- characterization of aerosols and gaseous pollutants downwind of the urban area of Houston,
- characterization of aerosols and gaseous pollutants in the mixed plumes of the urban area and the ship channel, and
- characterization of aerosols and gaseous pollutants in both continental and maritime air entering the Houston area.

MONITORING NETWORK

Two relocatable monitoring stations were used in this study, one of which could also be used in a mobile mode. Thirteen sites in and around the city of Houston were available for the daily placement of these stations. All thirteen of these sites plus ten other sites were also available for the placement of high volume air samplers (hivols) or Automatic Dichotomous Samplers (ADS). Eight hivols and five ADS units were used.

Table 1 lists the various sites which were available. The thirteen sites which had power hook-ups for the aerosol monitoring stations are specified in the "Extra Power Available" column. The location of the aerosol sites is depicted in Figure 1. With this variety of sites it was possible to place the stations at the ship channel, in the city, or in various upwind - downwind combinations for the predominant wind directions.

Pilot balloons were released hourly (approximately ten times daily) at two sites, one in the town of Pearland (Site 17) to the south of Houston, the other near the intersection of Loop 610 at Highway 290 on the northwest side of Houston (Site 24).

PREPLANNED EXPERIMENTS

The site location for each monitoring station, hivol, and ADS unit for a given day was selected at 4:00 p.m. the previous day during a planning session. A weather forecast for the following day was received daily before the planning session, and the type of experiment selected was based on this forecast and on the results of previous experiments.

The planning session was attended by the EPA project monitor, the Radian project director, and the Environmental Measurements, Inc. project director or task leader. Participants in the other EPA programs being conducted simultaneously in the area frequently attended the planning sessions also.

To aid in the planning session, a set of preplanned experiments was developed prior to the start of the field study. Placement sites were selected for the monitors so that the necessary information could be obtained for each wind direction. Three major areas of study parameters were defined:

- positions for the relocatable stations to collect data for various goals,
- experiments for chemical analysis of collected aerosols, and
- routes for the mobile station.

Nine basic types of experiments were preplanned utilizing different sites for the relocatable stations. These included:

- experiments to measure continental background without forest influence (three wind directions, three suggested sites),

TABLE 1. MONITORING SITES FOR EPA HOUSTON AIR POLLUTION STUDY - 1978

APS Site	Site Name	Approximate Address	Agency/ Group	Extra Power Available	Comments
1	Aldine	4600 Aldine Mail Route	TACB	Yes	Open area, TACB station fenced, school playground.
2	Mae Drive	Mae Dr. & IH 10	TACB	Yes	Fenced playground. Northwest of ship-channel, 1 block south of IH 10.
3	Crawford	Crawford & Polk	City of Houston	No	Downtown site near fire station. Southeast of street canyons. No fence.
4	Clinton Dr.	9525 Clinton Dr.	City of Houston	No	Northwest of ship channel, major artery and railroad. Fenced.
5	Parkhurst	8314 Parkhurst	City of Houston	No	Near water tank & trees. Fenced.
6	Lang	Lang & Bingle	City of Houston	Yes	
7	MacGregor	1115 MacGregor	City of Houston	No	Penthouse station on top of Health Department.
8	Fuqua	Fuqua & Telephone	City of Houston	No	Fenced. Near water tank.
9	Hornwood	Hornwood & US 59	EPA-VI	No	Laboratory in office building.
10	Pasadena	Ethyl Road North of S.H. 225	HL&P	No	Fenced enclosure.
11	Channelview	DeZavalle & Market Sts.	HL&P	No	Buildings & trees nearby - just north of ship channel. Station is fenced area.
12	Seabrook	609 El Jardin at Geraldine	EPA-VI	Yes	Open playground, no fence. ½ mile west of Galveston Bay.
13	Highlands	1112 E. Wallisville Rd. at Thompson Rd.	Aerosols	Yes	Open playground. Northwest of Exxon refinery complex 6 miles. No fence.
14	Canino	Canino & Alfano	Aerosols	Yes	Residential area with a few trees. No fence.
15	Westhollow	333 So. Hwy. 6	Shell	No	Fenced. No access except 8-5 p.m. Contact Jack Badley.
16	Beasley	South of Rosenberg on US 59	Monsanto	No	Remote site, 32 miles southwest of downtown Houston.
17	Pearland	2619 Pearland-Sites at Walnut	WSU II	Yes	Open parking lot of VFW hall. No fence. Parking lot active on Friday, Saturday & Sunday nights.
18	Fish Hatchery	Garrett Rd. & Canal	WSU I	Yes	Open area. No fence. At the Ranger Station.
19	Hobby	Braniff & Randolph	Aerosols	Yes	South side of Hobby Airport. Fenced.
20	Jackrabbit	FM 1960 at Jones Rd.	EPA-GPKB	Yes	Fenced. Open area. Gravel road.
21	Alief	12137 High Star at Cook	Aerosols	Yes	School grounds. No fence. Some loose dirt.
22	Baytown	310 W. Baker at Garth	Aerosols	Yes	School grounds. Open area.
23	Stude Park	942 USENER at Michaux	Aerosols	Yes	Open area across bayou from IH 10. Not fenced.
24	Brookhollow	4141 N Directors Row	Aerosols	No	Pibal site only. A few tall trees to southwest.

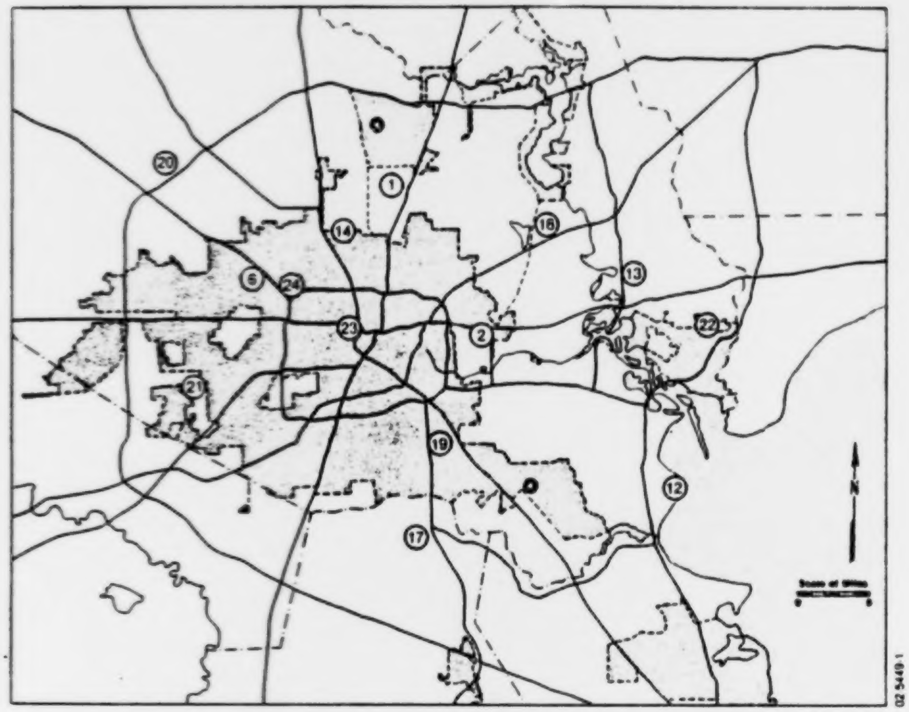

Figure 1. Location of the Aerosol Study Sites (Houston Aerosol Characterization Study, 1978).

- experiments to measure continental background with forest effect (one wind direction, four suggested sites),
- experiments to measure suburban aerosols (seven wind directions, twenty-six suggested site pairs),
- experiments to measure aerosol transport from the Baytown area (six wind directions, three suggested site pairs),
- experiments to measure aerosols upwind/downwind of the ship channel (five wind directions, eleven suggested site pairs),
- experiments to measure maritime background aerosols (two wind directions, five suggested site pairs),
- experiments to measure urban aerosols (six wind directions, twelve suggested site pairs),

- experiments to compare urban and ship channel plumes (four wind directions, eleven suggested site pairs), and

- experiments to measure mixed urban and ship channel plumes (four wind directions, nine suggested site pairs).

For the mobile station, seventeen different routes were planned to accommodate various wind directions and experiment goals. The mobile van was to be continually on the move during these tests, since a series of short stops would make it more difficult to separate temporal and spatial effects.

The chemical analysis studies involved both organic and inorganic sampling. The organic sampling utilized trapping of materials on special hivol and ADS filters, and trapping of organic vapors in resin-filled tubes (Tenax and XAD). The inorganic sampling utilized trapping solids on special hivol and ADS filters, and trapping vapors in impinger trains. Additional details on sampling procedures are given in Section 5.

Effects of relative humidity on aerosols were measured by using heated and unheated nephelometers, and by intermittently diluting the input to an electrical aerosol analyzer with clean, dry air.

On some days the planning group chose not to run experiments the following day. Conditions which led to this decision included the following:

- sufficient data had already been collected under the conditions forecast for the following day,

- the winds were expected to be so variable that interpretation of results would be impossible,

- multi-point calibrations were scheduled for the next day, and

- several analyzers were inoperative and time was needed for repairs.

QUALITY ASSURANCE

The quality assurance aspect of this program was designed to include the following elements:

- weekly multi-point calibrations of all continuous analyzers for gaseous pollutants,

- an independent audit (by a different contractor) of all analyzers one time during the one-month program (gaseous and aerosols),
- daily zero-span checks of all continuous analyzers,
- NBS - traceability for all reference materials (where applicable),
- daily flow calibrations of all hivol samplers,
- weekly flow calibration of all ADS units,
- weekly flow calibration of the optical particle counters,
- daily flow calibration of the electrical aerosol analyzers' collected rod voltage check,
- weekly calibration of the optical particle counter with polybeads,
- daily zero/span of the condensation nuclei counter.

SECTION 5

EXPERIMENTAL PROCEDURES

The Houston Aerosol Characterization Study used four major monitoring systems to collect a variety of experimental data. An instrumented relocatable trailer and an instrumented mobile laboratory were used to collect meteorological data and monitor real time aerosol size distributions and real time concentrations of gaseous pollutants. These systems also provided cumulative particulate mass data.

A network of conventional high volume samplers and automated dichotomous samplers were used to collect particulate and organic vapor samples. A pilot balloon sounding network was used to collect upper level wind and temperature data.

The remainder of this section describes the instrumentation and operation of each of the four monitoring systems. Integrated daily operation of all four monitoring systems is also discussed.

RELOCATABLE TRAILER

The relocatable trailer (R-28) used in this studv was an adaption of the Radian System I Air Quality Monitoring System. The shelter consisted of a 26-foot long, all steel, drop-frame van with a fifth-wheel-type hitch and air-ride suspension. An environmental control system with low power consumption maintained the internal temperature at 70°F. A cross-sectional view of the relocatable trailer is shown in Figure 2.

Meteorological Instrumentation

Trailer R-28 was equipped with meteorological instrumentation for measuring wind direction, wind speed, ambient temperature, dew point temperature, total solar radiation, ultraviolet solar radiation, barometric pressure, and rainfall. Wind, temperature, and dew point sensors were mounted on a 33-foot crankup tower, attached to the rear of the trailer.

Wind-sensors were mounted on a crossarm assembly on top of the tower, at a measurement height approximately 36 feet above

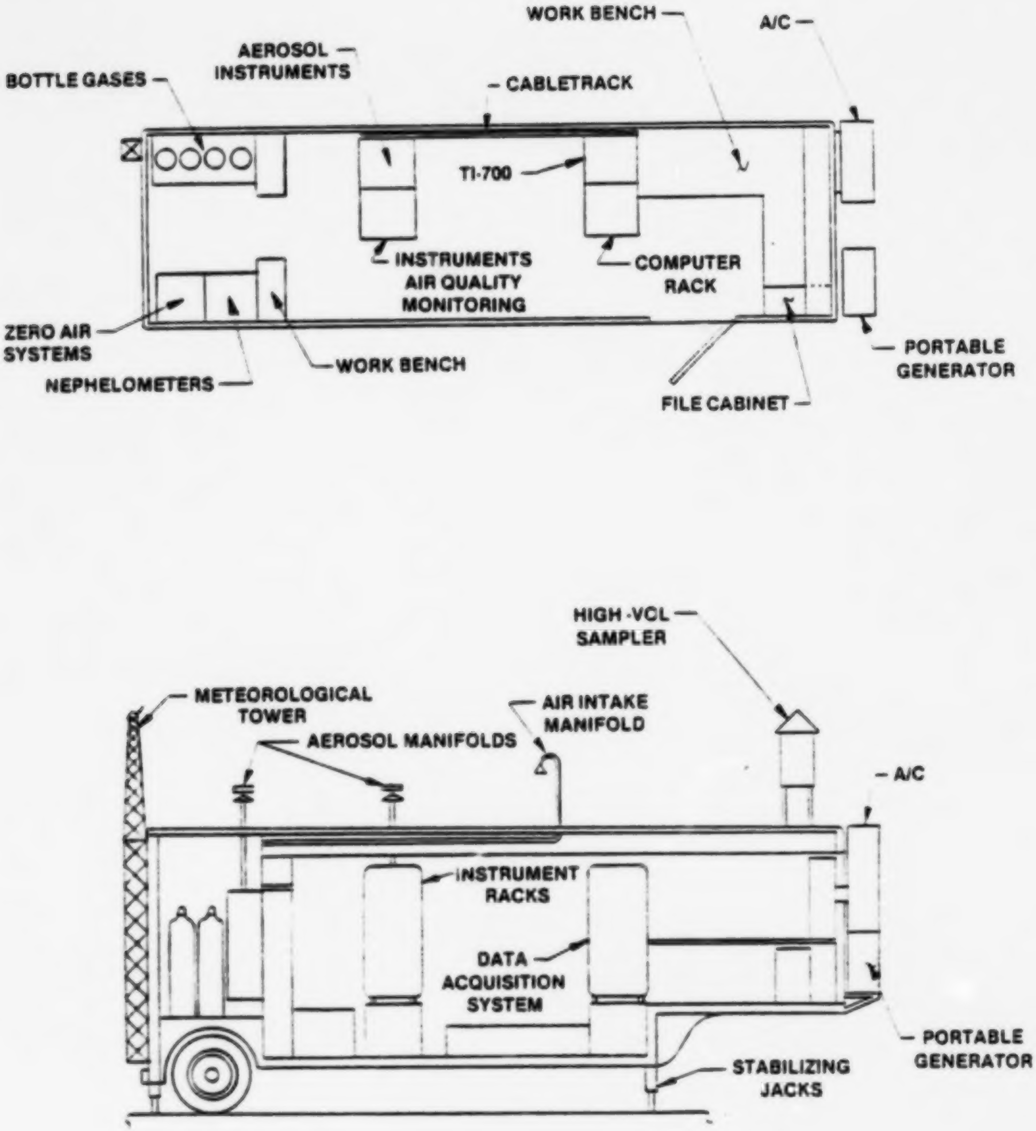
WORK BENCH
A/C
AEROSOL INSTRUMENTS
BOTTLE GASES
CABLETRACK
TI-700
INSTRUMENTS AIR QUALITY MONITORING
COMPUTER RACK
ZERO AIR SYSTEMS
NEPHELOMETERS
WORK BENCH
FILE CABINET
PORTABLE GENERATOR
HIGH-VOL SAMPLER
METEOROLOGICAL TOWER
AIR INTAKE MANIFOLD
AEROSOL MANIFOLDS
A/C
INSTRUMENT RACKS
DATA ACQUISITION SYSTEM
PORTABLE GENERATOR
STABILIZING JACKS

Figure 2. R-28 Relocatable Trailer (Houston Aerosol Characterization Study, 1978).

ground. Dew point temperature and ambient temperature sensors were at about 34 feet above ground. Two solar radiation instruments were mounted on the trailer roof; solar measurement height was about 16 feet above the ground.

A microbarograph was operated inside the trailer. A fence-post rain gauge was mounted in an unobstructed area outside the trailer. Rain gauge measurement height was about four feet above the ground.

Wind measurement instruments within the trailer were made by Weathermeasure Corporation. A model W103/3L cup anemomenter, which is a high response, low threshold wind system, was installed. Its threshold was 0.6 mph, and its distance constant was five feet. The anemomenter's accuracy was ±1 percent or ±0.15 mph, whichever was greater, and its translator range (recording range) was 0 to 100 mph.

The wind vane used was a model W104-2 light weight vane which operated in the 0° to 540° output range. This model had no dead band, a damping ratio of 0.4, a distance constant of 3.5 feet, and a starting threshold of 0.75 mph. The translators and printed circuit boards for each of these instruments were built by Radian Corporation.

A Climet Instruments Company Model CI-65 Temperature and Cooled Mirror Dew Point Hygrometer system was used in the trailer. A Climet Model 016-4 Motor-Aspirated Radiation Shield housed the hygrometer and temperature sensors. In this system, ambient temperature was measured by a Model 015-3 Thermistor, in which a platinum resistance probe was used to sense the dew point temperature. The temperature range (translator range) was -45°F to +122°F. The temperature accuracy was ±0.1°C and the temperature response was 10 seconds in air. The dew point temperature range of this instrument was -58°F to 122°F. The dewpoint accuracy was ±0.5°C and the dewpoint response was 0.5°C per second. The solid-state LED light source and dual mirror sensor allowed the dew point system to maintain accuracy in the presence of contaminants normally collected on the sampling mirror. A Climet Model 065-2-5 Translator, circuit boards for both temperature and dew point measurement, and a Climet Model 065-1 Junction Box were used in conjunction with the system.

Total solar radiation was measured by an Eppley Model 2 Pyranometer. Ultra-violet solar radiation was monitored with an Eppley Model TUVR Ultra-Violet Radiometer (photometer). Both were supplied by EPA.

The pyranometer range was 0 to 2 langleys per minute. Its wavelength range was 0.28μm to 2.8μm (total sun and sky radiation), and its sensitivity was approximately nine microvolts per watt meter^{-2}. The sensitivity was constant to within ±1 percent over an ambient temperature range of -4°F to 104°F. Response was linear up to intensities of four cal. cm^{-2} min^{-1}. Response time was 1 second.

The ultraviolet radiometer range was 0 to 0.1 langleys per minute, and its wavelength range was 0.295μm to 0.385μm. Its sensitivity was 150 microvolts per watt meter^{-2}, and its response time was in milliseconds. Radian-built signal amplifiers were used between the sensors and the digital data recording system.

Strip chart records of barometric pressure (station pressure) were obtained with a Weathertronics, Inc. Model 7010 Spring-Wound Microbarograph. The sensor accuracy was ±0.15 mb, and the recording range spanned 100 mb. The chart resolution was at least 0.2 mb (with 0.5 mb chart graduation). Full temperature compensation was accomplished with an aged bimetallic strip.

The fence post rain gauge used was a Weathertronics Model 6320. It was made of wedge-shaped, weather-resistant plastic and mounted in an aluminum bracket fastened by screws to a wood support. Its capacity was six inches, with graduation ranges from 0.01 inch for small amounts to 0.10 inch for large amounts of rainfall.

Gaseous Monitoring Equipment

The following paragraphs describe the equipment used during the study to monitor ozone, sulfur dioxide, and nitrogen oxides. EPA-approved methodology, if available, was used in collecting and analyzing gaseous samples.

Ozone--

A Meloy Laboratories Model OA350-2R Ozone Analyzer was used to monitor ozone concentrations during the study. This instrument was a continuous analyzer which determined ozone levels by chemiluminescence. Specifications for the ozone analyzer are listed below:

Ranges:	0-10 ppb
	0-100 ppb
	0-500 ppb (approved range)
	0-1000 ppb
	0-5000 ppb
	0-10,000 ppb
Minimum Detectable Sensitivity:	0.5 ppb

Zero Drive:	3.5 ppb per day on 500 ppb range
Span Drift:	Less than 1 percent per day
Linearity:	±1 percent
Operating Temperature:	50-104°F
Precision:	±2 percent

Sulfur Dioxide--

A Meloy Model SA185-2A Sulfur Dioxide Analyzer was used to measure ambient concentrations of sulfur dioxide. This instrument contained a flame photometric detector, which measured sulfur dioxide as a function of the intensity of light emitted at 394 nm by sulfur-containing compounds in a hydrogen-air flame.

Specifications for the analyzer are listed below:

Range:	0 to 0.5 ppm
Noise:	0.002 ppm
Minimum Detectable Concentration:	.002 ppm
Zero Drift (with Temperature Control):	±0.002 ppm (24 hours)
Span Drift (with Temperature Control):	±3 percent per day
Linearity:	± percent full scale
Precision:	0.001 ppm
Operating Temperature Range:	68-86°F
Interface Equivalent:	±0.01 ppm

Nitrogen Oxides--

Nitric oxide, nitrogen dioxide, and total nitrogen oxides were measured with a CSI Model 1600 Nitrogen Oxides Analyzer. This instrument, which determined nitrogen oxides levels by chemiluminescence, had the following specifications:

Ranges:	0.05, 0.10, 0.20, 0.50, 1.00, 2.00, and 5.00 ppm
Linearity:	±1 percent (24 hours)

Lower Detection Limit:	0.002 ppm
Noise:	0.001 ppm
Zero Drift:	±0.001 ppm (24 hours)
Span Drift:	±1 percent (24 hours)
Temperature Range:	50-140°F

Aerosol Instrumentation

Aerosol particle size classification over a range of 0.01 to 1.0 μm diameter was obtained using a TSI, Inc. 3030 Electrical Aerosol Size Analyzer (EAA) provided by EPA[9]. The EAA measured particle mobility within an electric field to provide a size classification of ambient aerosols. The aerosol particles were classified over eight logarithmically equal intervals. A complete size spectrum was obtained over a two-minute interval.

The EAA was maintained within a sealed housing (Figure 3), which served two purposes:

1) The sampled air and instrument were kept at near ambient temperatures to prevent condensation of moisture and subsequent change in aerosol size distribution.
2) The chamber served to reduce short time fluctuations in aerosol concentrations during the two-minute measurement period.

The temperature within the chamber was monitored using a thermocouple with a digital display, which allowed easy comparison with ambient temperature. A clear Plexiglas viewing port allowed the operator to observe the interior of the EAA for signs of condensation.

Real-time size distributions over the range of 0.3 to 10 μm were measured using an optical particle counting system consisting of a Climet 208 Particle Counter, a KIM-1 microcomputer manufactured by Mos Technology, Inc., and an analog/digital converter (Figure 4). This system[10], provided by EPA, classified particle size over 10 logarithmically equal intervals during each 10-minute acquisition period.

The Climet particle counter detected light scattered by single particles in the near forward direction over a solid angle of 5.1 steradians. The pulses resulting from the scattered light were counted as individual particles of a size reflected by the amplitude of the pulse. The analog/digital converter and microcomputer classified each pulse into a

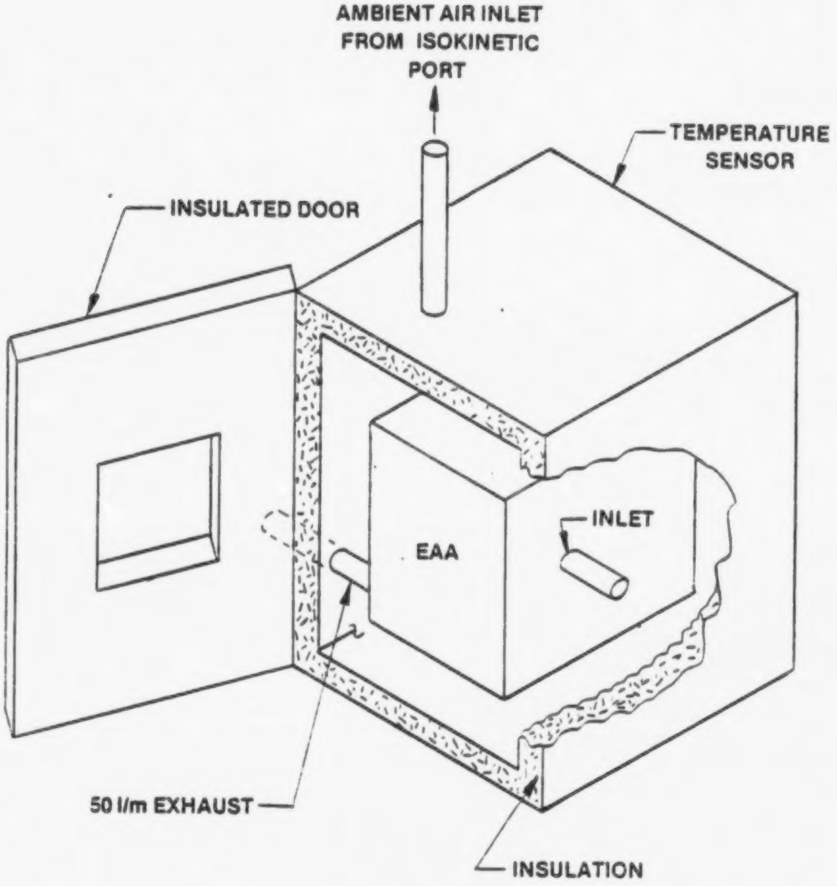
AMBIENT AIR INLET FROM ISOKINETIC PORT
TEMPERATURE SENSOR
INSULATED DOOR
INLET
EAA
50 l/m EXHAUST
INSULATION

Figure 3. Electrical Aerosol Sampling Chamber (Houston Aerosol Characterization Study, 1978).

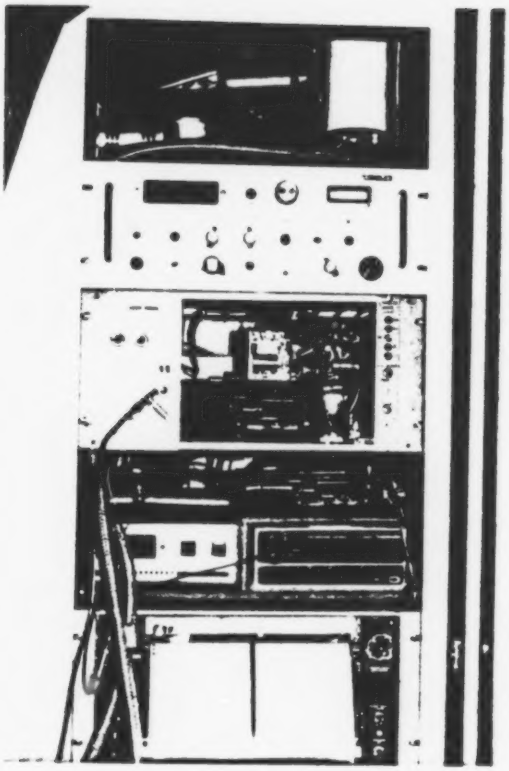

Figure 4. Optical Particle Counter and Microcomputer
(Houston Aerosol Characterization Study, 1978).

predetermined interval (1-19) over the 10-minute acquisition time (2).

For continuous measurement of condensation nuclei (particles greater than 0.003 μm in diameter), EPA provided an Environment One Condensation Nuclei Counter (CNC). In this instrument, a sampled aerosol stream was passed through a humidification chamber and into a cloud chamber, where it was expanded to a low pressure. The expansion of the humid aerosol sample allowed condensational growth of droplets on existing nuclei. Attenuation of light passed through the aerosol cloud was directly related to the number of condensation nuclei.

Two nephelometers, provided by EPA, were employed to measure particle scattering coefficient on a continuous basis. The nephelometers were manufactured by MRI and had recently been modified by Alan Waggoner at the University of Washington. The normal response range of the instrument was 0 to 5 volts, corresponding to a scattering coefficient of approximately 2.20×10^{-4} m^{-1}. However, Radian was advised that the response range could be extended to 0 to 10 volts with linear results.

An ambient air sample was drawn into a sealed, insulated chamber at a rate of approximately 60 cfm. One nephelometer sampled the air directly and was referenced as ambient temperature, while a second nephelometer sampled the air through a heated inlet prior to measuring the particle scattering coefficient (Figure 5). The temperature at each instrument was continuously monitored using a thermocouple with direct temperature readout.

Data Acquisition and Processing

A NOVA data acquisition and reduction system (Data General Corporation) provided real time display of meteorological and gaseous pollutant data. Each instrument was scanned once per second and the values averaged over a five-minute period. Values were stored on cassette tape, with hourly summaries printed on hardcopy. All values were reported in engineering units and reflected the current day's zero/span corrections. An example of the hourly data summary is shown in Figure 6. Aerosol data were recorded separately. The recorded data were collected daily for keypunching and input into Radian's Aerosol Data Reduction System. The output provided hourly averages of the recorded data. An example of an aerosol data summary is shown in Figure 7. The data processing algorithms are contained in Appendices C and D, Volume 2.

Sampling Systems

A 25-millimeter diameter Ace glass system was used in this study as a gaseous sampling manifold. The system air intake was

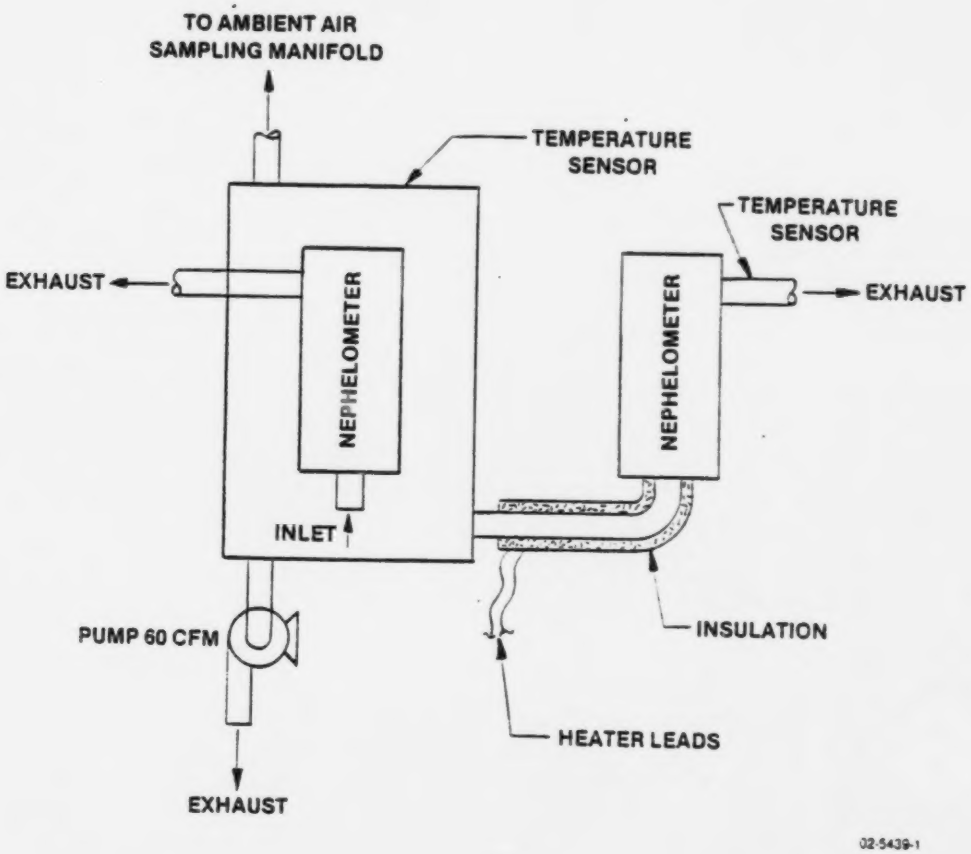
TO AMBIENT AIR
SAMPLING MANIFOLD
TEMPERATURE
SENSOR
TEMPERATURE
SENSOR
EXHAUST
NEPHELOMETER
NEPHELOMETER
EXHAUST
INLET
PUMP 60 CFM
INSULATION
HEATER LEADS
EXHAUST
02-5439-1

Figure 5. Heated and Unheated Nephelometer Sampling System (Houston Aerosol Characterization Study, 1978).

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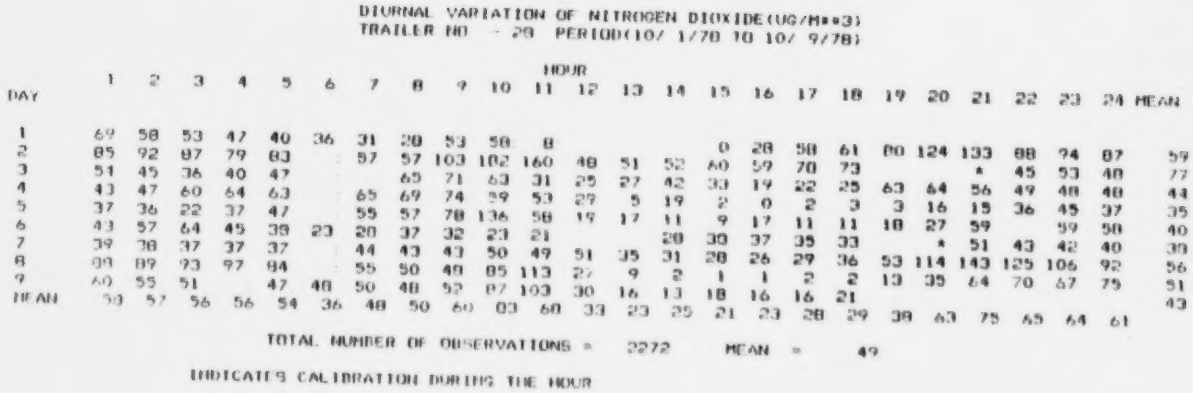


```
                              DIURNAL VARIATION OF NITROGEN DIOXIDE(UG/M**3)
                              TRAILER NO  - 28  PERIOD(10/ 1/78 TO 10/ 9/78)

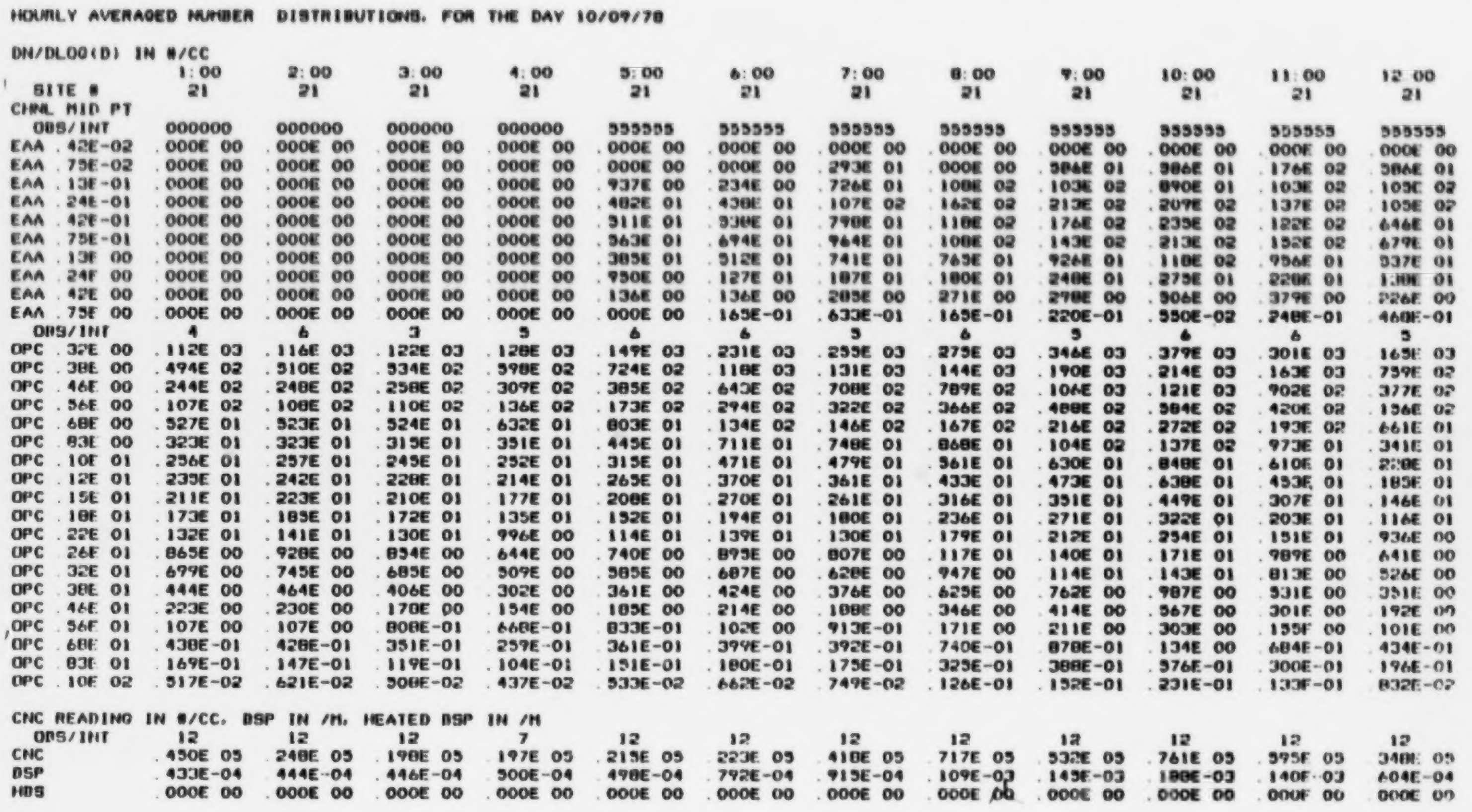
                                                 HOUR
        1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24 MEAN
DAY

 1     69  58  53  47  40  36  31  28  53  58   8               0  28  58  61  80 124 133  88  94  87   59
 2     85  92  87  79  83      57  57 103 102 160  48  51  52  60  59  70  73           *  45  53  48   77
 3     51  45  36  40  47          65  71  63  31  25  27  42  33  19  22  25  63  64  56  49  48  48   44
 4     43  47  60  64  63      65  69  74  59  53  27   5  19   2   0   2   3   3  16  15  36  45  37   35
 5     37  36  22  37  47      55  57  78 136  58  19  17  11   9  17  11  11  18  27  59      59  58   40
 6     43  57  64  45  38  23  28  37  32  23  21          28  38  37  35  33       *  51  43  42  40   38
 7     39  38  37  37  37      44  43  43  50  49  51  35  31  28  26  29  36  53 114 143 125 106  92   56
 8     89  89  93  97  84      55  50  49  85 113  27   9   2   1   1   2   2  13  35  64  70  67  75   51
 9     60  55  51      47  48  50  48  52  87 103  30  16  13  18  16  16  21                           43
MEAN   58  57  56  56  54  36  48  50  60  83  60  33  23  25  21  23  28  29  38  63  75  65  64  61

                    TOTAL NUMBER OF OBSERVATIONS =   2272     MEAN =     49

               INDICATES CALIBRATION DURING THE HOUR
```

Figure 6. Example of Hourly Data Summary (Houston Aerosol Characterization Study, 1978).



```
HOURLY AVERAGED NUMBER  DISTRIBUTIONS. FOR THE DAY 10/09/78

DN/DLOG(D) IN #/CC
               1:00      2:00      3:00      4:00      5:00      6:00      7:00      8:00      9:00     10:00     11:00     12:00
  SITE #        21        21        21        21        21        21        21        21        21        21        21        21
CHNL MID PT
  OBS/INT     000000    000000    000000    000000    555555    555555    555555    555555    555555    555555    555555    555555
EAA .42E-02  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00
EAA .75E-02  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .293E 01  .000E 00  .384E 01  .386E 01  .176E 02  .386E 01
EAA .13E-01  .000E 00  .000E 00  .000E 00  .000E 00  .937E 00  .234E 00  .726E 01  .108E 02  .103E 02  .890E 01  .103E 02  .105E 02
EAA .24E-01  .000E 00  .000E 00  .000E 00  .000E 00  .482E 01  .438E 01  .107E 02  .162E 02  .213E 02  .209E 02  .137E 02  .105E 02
EAA .42E-01  .000E 00  .000E 00  .000E 00  .000E 00  .311E 01  .538E 01  .798E 01  .118E 02  .176E 02  .235E 02  .122E 02  .646E 01
EAA .75E-01  .000E 00  .000E 00  .000E 00  .000E 00  .563E 01  .694E 01  .964E 01  .108E 02  .143E 02  .213E 02  .152E 02  .679E 01
EAA .13E 00  .000E 00  .000E 00  .000E 00  .000E 00  .385E 01  .512E 01  .741E 01  .763E 01  .926E 01  .118E 02  .956E 01  .537E 01
EAA .24E 00  .000E 00  .000E 00  .000E 00  .000E 00  .950E 00  .127E 01  .187E 01  .180E 01  .248E 01  .275E 01  .220E 01  .138E 01
EAA .42E 00  .000E 00  .000E 00  .000E 00  .000E 00  .136E 00  .136E 00  .285E 00  .271E 00  .278E 00  .306E 00  .379E 00  .226E 00
EAA .75E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .165E-01  .633E-01  .165E-01  .220E-01  .550E-02  .248E-01  .460E-01
  OBS/INT        4         6         3         5         6         6         5         6         5         6         6         5
OPC .32E 00  .112E 03  .116E 03  .122E 03  .128E 03  .149E 03  .231E 03  .255E 03  .275E 03  .346E 03  .379E 03  .301E 03  .165E 03
OPC .38E 00  .494E 02  .510E 02  .534E 02  .598E 02  .724E 02  .118E 03  .131E 03  .144E 03  .190E 03  .214E 03  .163E 03  .759E 02
OPC .46E 00  .244E 02  .248E 02  .258E 02  .309E 02  .385E 02  .643E 02  .708E 02  .789E 02  .106E 03  .121E 03  .902E 02  .377E 02
OPC .56E 00  .107E 02  .108E 02  .110E 02  .136E 02  .173E 02  .294E 02  .322E 02  .366E 02  .488E 02  .584E 02  .420E 02  .156E 02
OPC .68E 00  .527E 01  .523E 01  .524E 01  .632E 01  .803E 01  .134E 02  .146E 02  .167E 02  .216E 02  .272E 02  .193E 02  .661E 01
OPC .83E 00  .323E 01  .323E 01  .315E 01  .351E 01  .445E 01  .711E 01  .748E 01  .868E 01  .104E 02  .137E 02  .973E 01  .341E 01
OPC .10E 01  .256E 01  .257E 01  .245E 01  .252E 01  .315E 01  .471E 01  .479E 01  .561E 01  .630E 01  .848E 01  .610E 01  .220E 01
OPC .12E 01  .235E 01  .242E 01  .228E 01  .214E 01  .265E 01  .370E 01  .361E 01  .433E 01  .473E 01  .638E 01  .453E 01  .185E 01
OPC .15E 01  .211E 01  .223E 01  .210E 01  .177E 01  .208E 01  .270E 01  .261E 01  .316E 01  .351E 01  .449E 01  .307E 01  .146E 01
OPC .18E 01  .173E 01  .185E 01  .172E 01  .135E 01  .152E 01  .194E 01  .180E 01  .236E 01  .271E 01  .322E 01  .203E 01  .116E 01
OPC .22E 01  .132E 01  .141E 01  .130E 01  .996E 00  .114E 01  .139E 01  .130E 01  .179E 01  .212E 01  .254E 01  .151E 01  .936E 00
OPC .26E 01  .865E 00  .928E 00  .834E 00  .644E 00  .740E 00  .895E 00  .807E 00  .117E 01  .140E 01  .171E 01  .989E 00  .641E 00
OPC .32E 01  .699E 00  .745E 00  .685E 00  .509E 00  .585E 00  .687E 00  .628E 00  .947E 00  .114E 01  .143E 01  .813E 00  .526E 00
OPC .38E 01  .444E 00  .464E 00  .406E 00  .302E 00  .361E 00  .424E 00  .376E 00  .625E 00  .762E 00  .987E 00  .531E 00  .351E 00
OPC .46E 01  .223E 00  .230E 00  .170E 00  .154E 00  .185E 00  .214E 00  .188E 00  .346E 00  .414E 00  .567E 00  .301E 00  .192E 00
OPC .56E 01  .107E 00  .107E 00  .808E-01  .668E-01  .833E-01  .102E 00  .913E-01  .171E 00  .211E 00  .303E 00  .155E 00  .101E 00
OPC .68E 01  .438E-01  .428E-01  .351E-01  .259E-01  .361E-01  .399E-01  .392E-01  .740E-01  .878E-01  .134E 00  .684E-01  .434E-01
OPC .83E 01  .169E-01  .147E-01  .119E-01  .104E-01  .151E-01  .180E-01  .175E-01  .325E-01  .388E-01  .576E-01  .300E-01  .196E-01
OPC .10E 02  .517E-02  .621E-02  .508E-02  .437E-02  .533E-02  .662E-02  .749E-02  .126E-01  .152E-01  .231E-01  .133E-01  .832E-02

CNC READING IN #/CC. BSP IN /M. HEATED BSP IN /M
  OBS/INT       12        12        12         7        12        12        12        12        12        12        12        12
CNC          .450E 05  .248E 05  .198E 05  .197E 05  .215E 05  .223E 05  .418E 05  .717E 05  .532E 05  .761E 05  .595E 05  .348E 05
BSP          .433E-04  .444E-04  .446E-04  .500E-04  .498E-04  .792E-04  .915E-04  .109E-03  .145E-03  .188E-03  .140E-03  .604E-04
HBS          .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00  .000E 00
```

Figure 7. Example of Aerosol Data Summary (Houston Aerosol Characterization Study, 1978).

through a glass cone with an inverted funnel, located about three feet above the shelter roof. The manifold inside the shelter was contained in a heated chamber to prevent condensation of water. Individual 0.25-inch Teflon lines connected the manifold with each instrument. Ambient air was drawn through the manifold by a 60 cfm blower.

Sample air was brought to the aerosol sampling system through two separate manifold systems. One system provided sample to the Climet Optical Particle Counter, TSI Electrical Aerosol Analyzer and Environment One Condensation Nuclei Counter. The second system delivered sampler air to two MRI Integrating Nephelometers. Each system consisted of a four-foot section of three-inch diameter PVC tubing, with an inlet cap providing protection against rain, bugs, and other foreign matter (Figure 8). The inlet cap was designed to provide effective sample collection for particles less than 15 μm diameter at wind velocities from 0 to 10 mph. However, the actual sampling efficiency as a function of both particle size and wind speed has not been measured.

Standard high volume blowers were regulated to provide flow rates of 60 cfm through the systems. An orifice meter with magnehelic was used to monitor the flow rate. Isokinetic sampling nozzles were used to provide representative samples to the OPC, EAA, and CNC (Figure 9). A thermocouple was installed at the site where the isokinetic nozzles were located to monitor the temperature of the sampled air. The high relative humidity in Houston necessitated that all sampling streams be maintained at ambient temperatures to prevent condensation of moisture. Sampling manifolds were heated to match ambient temperature.

Calibration Systems

The relocatable trailer air monitoring system was equipped with a Meloy Model CNS-1 (RAD-1) Calibrator, which was computer controlled to produce daily, single-point span inputs to the sulfur dioxide and nitrogen oxide analyzers. Sulfur dioxide span gas was generated from a sulfur dioxide permeation tube contained in a temperature-controlled oven. Nitric oxide span gas was produced by capillary-controlled dilution of nitric oxide and nitrogen in zero air. The ozone analyzer used in this study contained an internal zero-span source which was referenced at least monthly during multipoint calibration.

All flows were measured using an NBS-traceable flow measuring device, such as a bubblemeter or mass flowmeter. All gaseous standards were traceable to National Bureau of Standards Standard Reference Materials (NBS-SRMs).

Multipoint calibrations were performed with a Bendix 8852 Calibrator, in which an ultraviolet lamp was used to generate

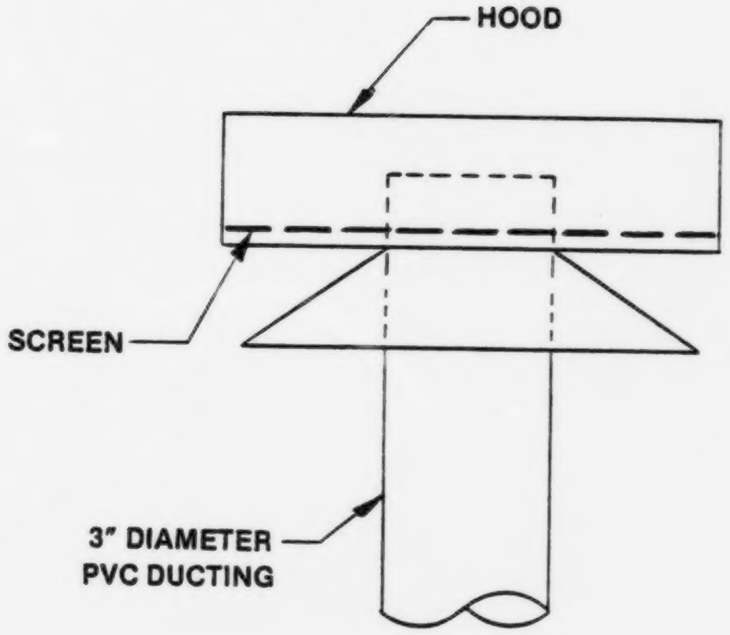

HOOD
SCREEN
3" DIAMETER PVC DUCTING

Figure 8. Aerosol Sampling Head (Houston Aerosol Characterization Study, 1978).

known quantities of ozone. Ozone calibration sources were referenced by the Neutral Buffered Potassium Iodine (NBKI) Method (Appendix E).

Specifications for the Bendix 8852 calibrator are listed below:

Precision:	±2 percent
Drift:	±1 percent/2 hours
Flow rates:	
Purge	5-500 cc/minute
Span	2-12 cc/minute
Dilution	200-8500 cc/minute

AIR QUALITY MOBILE LABORATORY

The Air Quality Mobile Laboratory (AQML) provided by EPA[11] for this study was a General Motors Transmode van converted for monitoring gaseous and particulate pollutants (Figure 10). The AQML was equipped with dual 6-KW electrical generators to supply power to instrumentation during mobile sampling. Continuous data were logged using an onboard minicomputer system (MAP III) and later converted to engineering units. A Hewlett Packard System 45 Desk Top Computer was used to acquire aerosol-size spectra and display the results. The MAP III system provided location data to which the pollutant measurements were referenced.

Because the onboard instruments received severe jolts during mobile sampling in Houston, the EPA advised Radian to operate the AQML primarily in a stationary mode. During stationary operation, sample air was delivered to the instrumentation through three sampling manifolds. The manifolds drew air samples from approximately three feet above the roof of the AQML and delivered the sample to:

1) aerosol instrumentation consisting of an EAA, OPC, and integrating nephelometer;

2) gaseous pollutant instrumentation including a sulfur dioxide analyzer, a nitrogen oxides analyzer, and two ozone analyzers;

3) an automated dichotomous sampler.

Forward-facing probes provided samples to the gaseous and aerosol sample manifolds during mobile sampling. The sample inlet for the gaseous pollutants consisted of an aluminum cone attached to

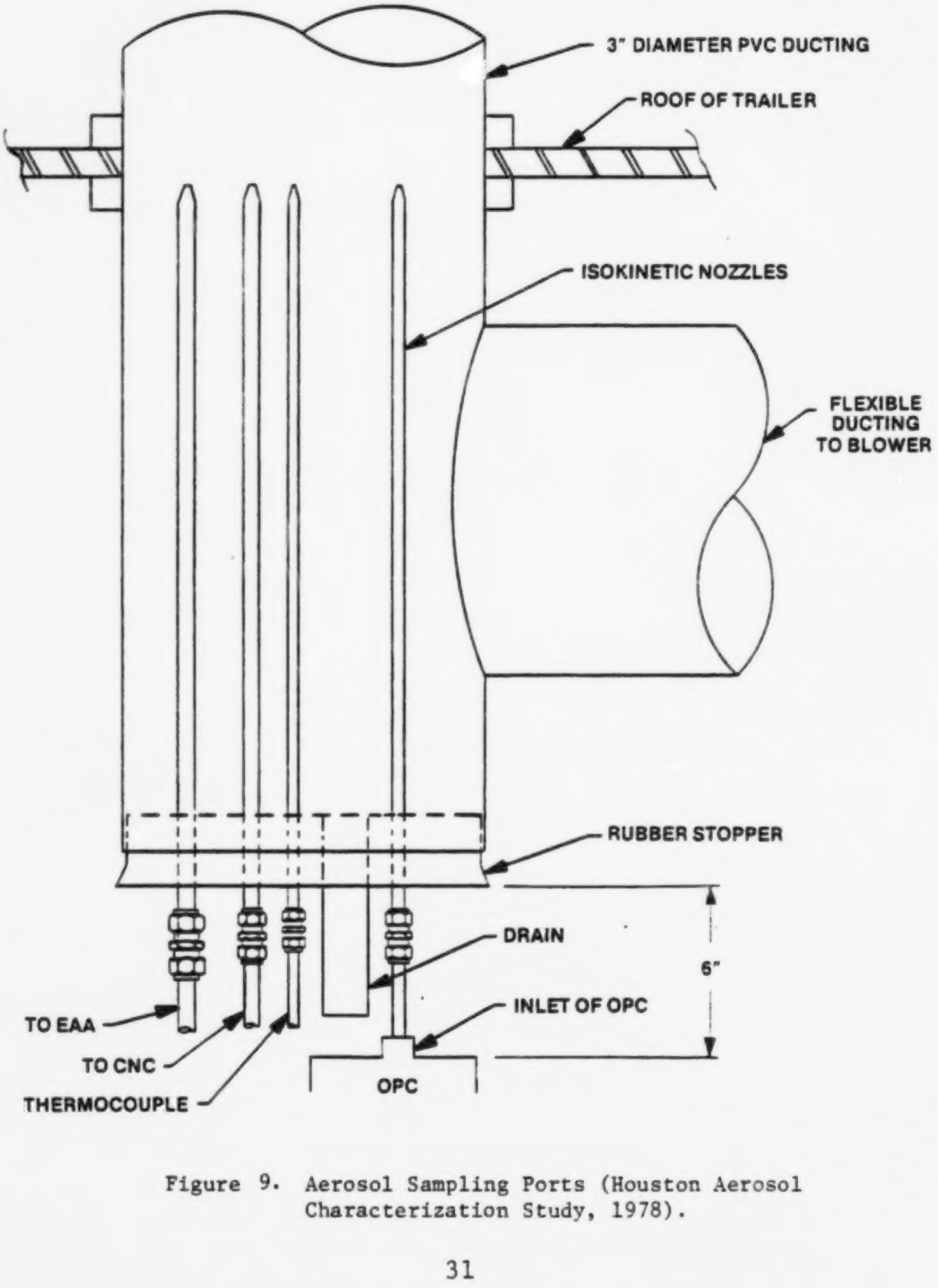

3" DIAMETER PVC DUCTING
ROOF OF TRAILER
ISOKINETIC NOZZLES
FLEXIBLE DUCTING TO BLOWER
RUBBER STOPPER
DRAIN
6"
INLET OF OPC
TO EAA
TO CNC
THERMOCOUPLE
OPC

Figure 9. Aerosol Sampling Ports (Houston Aerosol Characterization Study, 1978).

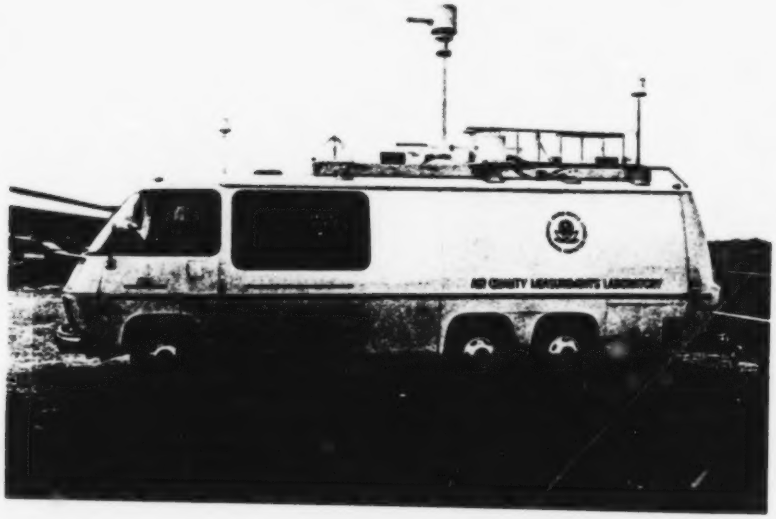

AIR QUALITY MEASUREMENTS LABORATORY

Figure 10. Air Quality Mobile Laboratory (AQML) (Houston Aerosol Characterization Study, 1978).

a glass sample manifold. The aerosol manifold used isokinetic nozzles to deliver representative samples to individual instruments. Measurements of its sampling efficiency have shown that its 50% cutpoint occurs at 6 μm (geometric) diameter. The measured particle size distributions have not been corrected for this effect.

Gaseous Pollutant Instrumentation

Continuous sulfur dioxide measurements were made using a Meloy Laboratory Model SA285 Total Sulfur Analyzer. This instrument used a flame photometric technique to detect sulfur species.

A Columbia Scientific Industries Model 1600 NO_x Monitor provided continuous measurement of nitric oxide and nitrogen oxides. Nitrogen dioxide values were obtained by difference. The monitor employed a chemiluminescent technique to measure nitrogen oxides.

Ambient ozone measurements were obtained with two separate instruments. One, a Bendix Model 8002 Ozone Monitor, employed a chemiluminescent technique, while the second, a Dasibi Model 1003AH Ozone Analyzer, utilized a photometric technique.

Aerosol Instrumentation

Included on board the AQML was aerosol instrumentation similar to that described for the relocatable trailer. The TSI Model 3030 Electrical Aerosol Analyzer was housed in a chamber similar to the one previously described. A two-minute size spectrum was obtained approximately every five minutes.

The Climet Optical Partical Counter was programmed[10] via the KIM microcomputer to acquire data over a five-minute time interval. Data from both the EAA and the OPC were stored in the HP-9845 system.

A single MRI Integrating Nephelometer provided particle scattering coefficient data. The instrument was maintained at near ambient temperatures.

HIGH VOLUME AND AUTOMATED DICHOTOMOUS SAMPLER (ADS) NETWORKS

A total of ten high volume air samplers were used during the study.[12] The samplers were deployed in pairs on a daily basis. Each pairing consisted of a sampler with a Gelman A (glass) filter for mass concentration measurements and a sampler with a Gelman Microquartz filter for organic chemical analysis. This arrangement minimized handling and possible contamination of the Microquartz filters. Samplers were operated at a nominal 60 cfm over 12-hour periods from 6:00 a.m. to 6:00 p.m. and/or 6:00 p.m. to 6:00 a.m.

The Automated Dichotomous Sampler (ADS) network consisted of four Beckman Laboratory samplers[13] and one Lawrence Berkley Laboratory (LBL) ADS[14] which were loaded onboard the AQML. EPA provided the Beckman and the LBL sampler, both of which used a virtual impaction technique to classify particulates into two size ranges. The Beckman samplers classified samples into a fraction less than 2.5µm in diameter (respirable particles), and into a fraction between 2.5µm and 15µm in diameter (inhalable particles). The LBL sampler measured particles between 2.4 µm and 15µm in diameter. Both models achieved the 15µm diameter classification by means of inertial separation of the sampling inlet.

The Beckman ADS consisted of a protective main housing which contained a microprocessor control circuit, a printer for data recording and display, filter changer mechanism, pumps and flow control units, virtual impactor, and thermostat control system. The size fractionating sampling inlet and sample delivery tube protruded approximately two feet above the top of the main housing. The individual filters were 37-mm diameter Teflon with a 2 µm pore size. The filters were frame-mounted on two-inch by two-inch slides. The filters were stored in filter trays which were compatible with the filter changer mechanism.

Two of the Beckman samplers were mounted on a specially constructed portable trailer (Figure 11). At the request of EPA personnel, these units were modified to provide storage of sampler filters at approximately 32°F using a refrigerated fluid. A dry nitrogen gas purge was also used to prevent condensation of water on the samples. These instruments were returned to normal operation midway through the sampling program.

The Beckman samplers were operated at a flow rate of 0.6 cfm over periods of 3, 6, and 12 hours. The LBL ADS was operated at 1.8 cfm for similar durations. High volume and ADS sampling periods were coordinated to simplify data interpretation. All samples were delivered to EPA laboratories for X-ray fluorescent and soluble species analyses.

When the AQML was in a stationary sampling mode, particulate samples were obtained for future chemical analysis using the LBL ADS. Samples were acquired semi-monthly over a 3-, 6-, or 12-hour period.

At various times during the study, samples were collected on Tenax resin for organic vapor analyses. The Tenax vapor traps (Figure 12) were run together with a high volume sampler with microquartz filter. Tenax samples were collected at a point following the high volume filter. Flow through the vapor trap was maintained by a critical orifice during 12-hour sampling periods. Following sample collection, the vapor traps were

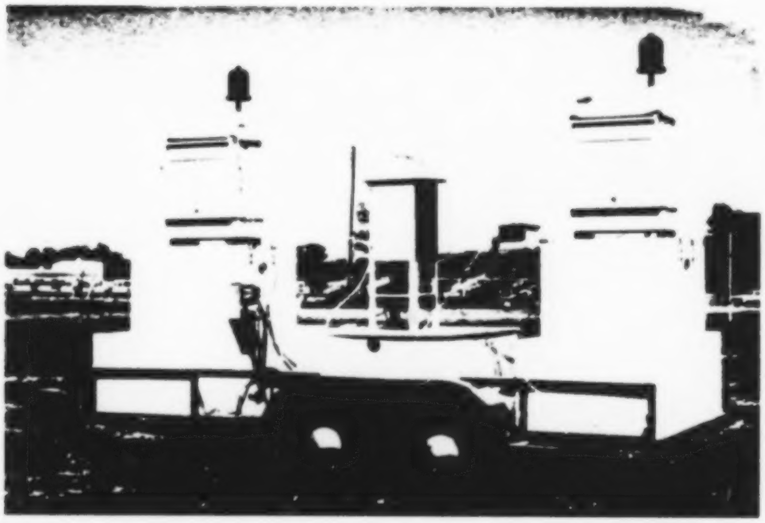


Figure 11. Mounted Beckman Samplers (Houston Aerosol Characterization Study, 1978).

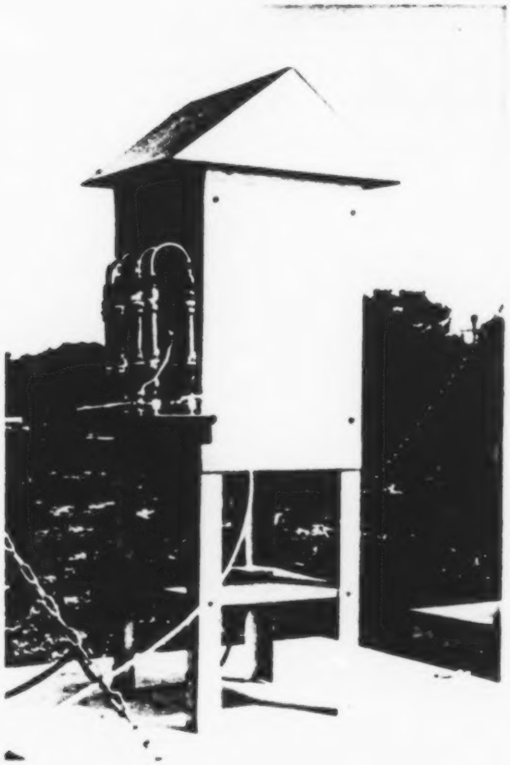


Figure 12. Tenax Vapor Traps Installed on a Hivol
(Houston Aerosol Characterization Study, 1978).

placed in cold storage and shipped to EPA for organic analysis by gas chromatography-mass spectroscopy. Methodology used in collecting the Tenax samples is described in detail in Appendix H.

In an effort to ensure sample integrity and prevent contamination, filter handling protocols were established for both the quartz fiber filters, Tenax GC traps, and the ADS filters. Research Triangle Institute (RTI), the contractor responsible for the study's organic analysis work, provided Radian with an itemized protocol for handling of organic sample collection media (Appendix H). This protocol included instructions detailing the collection period, filter storage, filter labeling and coding and shipment of the samples.

Radian analyzed blank microquartz filters and determined that the organic loading was greater than desired and highly variable on a per filter basis. Because of this variability, a filter cleaning procedure was established which brought the background to within an acceptable range and made the organic loading on each filter more consistent. The organic background loadings before and after cleaning, along with the exact cleaning procedures,are presented in Appendix G.

Radian field technicians followed the RTI protocol throughout the sampling program. The filters and/or filter holders were always handled with forceps and/or disposable finger cots rinsed with methylene chloride. Efforts were to ensure that the samples were not directly exposed during handling to contaminating sources including cigarette smoke, automobile exhaust, or organic vapors.

The ADS handling protocol was provided by the EPA laboratory responsible for X-ray fluorescent analysis (Appendix F). The protocol included a description of the ADS operation, along with the procedures required to ensure that the samples could be automatically processed through the XRF analysis system. The protocol also included details of the sample packaging, storage and shipment.

UPPER AIR MONITORING

Upper level wind and temperature soundings were obtained with pilot balloons (pibals) at two Houston area sites. The pilot balloon sounding program was designed to provide real time surface and upper level wind speed, wind direction, and temperature data. These data could be used to determine atmospheric conditions and to support detailed air pollutant transport studies.

A maximum of ten pilot balloon runs were conducted daily at each of the two sites. Wind speed and wind direction soundings were obtained from each of the runs, while temperature soundings were obtained from a maximum of two of the ten daily runs at each site. The pilot balloon runs were scheduled hourly, starting at 7:00 a.m. CDT and ending at 5:00 p.m. CDT (excluding the noon hour). Temperature soundings were obtained only from the 7:00 a.m. or 8:00 a.m. runs and the 1:00 p.m. run. Temperature soundings were scheduled during the early morning to reveal low inversion conditions, which are a major cause of the often poor early morning dispersion conditions. Afternoon temperature soundings were scheduled because they are important in the characterization of peak dispersion conditions.

One pilot balloon site (Site 24) was the lawn in front of the Radian Houston office, located at 4141H Directors Row, near the intersection of Interstate 610 and U.S. 290. This site is about six miles northwest of downtown Houston. Site 24 was representative of those sections of the Houston area which are far enough inland to be considered, meteorologically, relatively continental, i.e., the influence of the Gulf of Mexico is much less pronounced than in areas near the coast. The other pilot balloon site was at site #17 in Pearland. This site was sufficiently close to the coast to be considered relatively marine, since sea/land breeze effects, which can be evident to a depth of several thousand feet, were much stronger than at site 24.

To obtain wind speed and wind direction soundings, the pilot balloons were tracked by means of the single optical theodolite method, which requires an assumed ascent rate of the balloon. For this study, the 0.07 pound pilot balloons were filled with an amount of helium which results in an assumed ascent rate of approximately 600 feet per minute. In reality, the balloons' ascent rates varied due to atmospheric turbulence, induced primarily by convective currents. The variation in ascent rate introduced some uncertainty into the height of the balloons at any given time.

As the pilot balloon observer tracked a balloon, he read from the theodolite the azimuth and elevation angles at 30-second intervals. These data were indicated by timer signals prerecorded on a portable cassette recorder. These raw data were read into another portable cassette recorder, from which the data were later transferred to data forms. When real time data reduction was desired, the azimuth and elevation angles were entered into a Texas Instruments TI-59 Programmable Calculator, whose output was wind speeds and wind directions as a function of height.

For pilot balloons from which temperature soundings were desired, a TS-1 T-sonde (temperature sensor) was attached to the balloon. A thermistor in the T-sonde sensed temperature, which was converted to a radio signal. This signal was tracked by a ground-based TSR-2 Receiver/Demodulator. The receiver unit recorded temperature versus time on a strip chart recorder. The receiver was also used for calibration of the T-sonde prior to balloon launch. When real time data reduction was desired, strip chart data was transferred to plots of temperature versus height. These plots quickly revealed layers of differing stability in the atmosphere.

Wind speed and wind direction calculations were made for every 30 seconds after a pilot balloon launch. The methodology used in making these calculations is described in detail in Appendix I.

QUALITY ASSURANCE AUDITS

Quality assurance audits were performed on the criteria pollutant monitors, the aerosol instrumentation, and the meteorological sensors at both R-28 and the AQML. The criteria pollutant monitors, nephelometers, and the meteorological sensors were audited by the Research Triangle Institute on October 1, 1978, at both R-28 and the AQML[15]. Generally excellent results were obtained at both stations although only a few audit samples were provided and analyzed.

The audit results for the criteria pollutant monitors in R-28 are given in Table 2. It can be seen that excellent agreement with the audit values was obtained. The results for the AQML are given in Table 3. In this case, excellent results were obtained except for the carbon monoxide analyzer. The data from this instrument are not included in this report.

Audit results for the nephelometers at both R-28 and the AQML are given in Table 4. The audit involved a one-point span check of these analyzers, and acceptable results were obtained for both units.

Audit results for the high volume air samplers are given in Table 5. It can be seen that there was excellent agreement for both hivols.

The meteorological sensor audit results are given in Table 6. Again, excellent agreement was found between the audit values and the indicated values.

Audits of the electrical aerosol analyzers and the optical particle counters were performed by Northrop (personal written communication from Larry Cupitt, Northrop). Unfortunately the EAA in station R-28 was inoperative on the day of the audit. The EAA in the AQML was audited on September 28, 1978. Relevant test results are given in Table 7. The auditor's evaluation was "Data from EAA was being monitored correctly. Ionizer current was low during audit, but may have been humidity effect. Data

TABLE 2. AUDIT RESULTS FOR STATION R-28 (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

Analyzer Model and S/N	Audit Parameter	Analyzer Range	Audit Concentration ppm	Analyzer Response ppm	Difference Audit - Analyzer		Regression of Analyzer Response on Audit Concentration - Y = mX + b		
					ppm	Percent	Slope	Intercept	Correlation Coefficient
Meloy Model OA350 S/N 6H077	Ozone	0 to 0.5 ppm	0.000	0.001	0.001	---	0.9791	0.005	0.9998
			0.041	0.046	0.005	12.2			
			0.099	0.103	0.004	4.0			
			0.190	0.193	0.003	1.6			
			0.281	0.283	0.002	0.7			
			0.383	0.376	-0.007	- 1.8			
CSI Model 1600 S/N 8858	Nitric Oxide	0 to 0.5 ppm	0.000	0.004	0.004	---	0.9721	0.004	0.9999
			0.059	0.062	0.003	5.1			
			0.137	0.135	-0.002	- 1.5			
			0.246	0.247	0.001	0.4			
			0.348	0.342	-0.006	- 1.7			
			0.481	0.471	-0.010	- 2.1			
	Nitrogen Oxides	0 to 0.5 ppm	0.000	0.003	0.003	---	0.9689	0.005	0.9999
			0.059	0.064	0.005	8.5			
			0.137	0.136	-0.001	- 0.7			
			0.246	0.248	0.002	0.8			
			0.348	0.341	-0.007	- 2.0			
			0.481	0.470	-0.011	- 2.3			
Meloy Model 185 S/N 4C167	Sulfur Dioxide	0 to 0.2 ppm	0.000	0.000	0.000	---	0.8705	-0.003	0.9999
			0.047	0.037	-0.010	-21.3			
			0.153	0.128	-0.025	-16.3			
			0.246	0.212	-0.034	-13.8			
			0.363	0.312	-0.051	-14.0			
			0.455	0.395	-0.060	-13.2			

Source: Pasquini, Murdoch, Michie, Sexton[14]

TABLE 3. AUDIT RESULTS FOR STATION AQML (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

Analyzer Model and S/N	Audit Parameter	Analyzer Range	Audit Concentration ppm	Analyzer Response ppm	Difference Audit - Analyzer		Regression of Analyzer Response on Audit Concentration - Y = mX + b		
					ppm	Percent	Slope	Intercept	Correlation Coefficient
Bendix Model 8002 S/N 302070-3	Ozone	0 to 0.2 ppm	0.000	0.001	0.001	---	0.9501	0.005	0.9977
			0.026	0.030	0.004	15.4			
			0.065	0.070	0.005	7.7			
			0.102	0.109	0.007	6.9			
			0.142	0.140	-0.002	- 1.4			
			0.175	0.167	-0.008	- 4.6			
Dasibi Model 1003AH S/N 1991	Ozone	0 to 1.0 ppm	0.000	-0.009	-0.009	---	1.0570	-0.011	0.9990
			0.026	0.023	-0.003	-11.5			
			0.102	0.088	-0.014	-13.7			
			0.175	0.171	-0.004	- 2.3			
			0.249	0.252	0.003	1.2			
			0.358	0.380	0.022	6.1			
			0.414	0.420	0.006	1.4			
CSI Model 1600 S/N 0195	Nitric Oxide	0 to 0.5 ppm	0.000	-0.001	-0.001	---	1.0183	-0.004	0.9999
			0.068	0.064	-0.004	- 5.9			
			0.161	0.156	-0.005	- 3.1			
			0.244	0.243	-0.001	- 0.4			
			0.339	0.342	0.003	0.9			
			0.445	0.450	0.005	1.1			
	Nitrogen Oxides	0 to 0.5 ppm	0.000	-0.001	-0.001	---	1.0292	-0.003	0.9999
			0.068	0.067	-0.001	- 1.5			
			0.161	0.161	0.000	0.0			
			0.244	0.247	0.003	1.2			
			0.339	0.347	0.008	2.4			
			0.445	0.456	0.011	2.5			
Aerovitronics PhilcoFord S/N 009628	Carbon Monoxide	0 to 50 ppm	0.00	3.00	3.00	---	0.3269	2.994	0.9984
			3.68	3.85	0.17	4.6			
			7.75	6.00	-1.75	-22.6			
			20.75	9.75	-11.00	-53.0			
			30.61	12.75	-17.86	-58.3			
			40.11	16.25	-23.86	-59.5			
			0.00	1.75	1.75	---			

Source: Pasquini, Murdoch, Michie, Sexton[14]

TABLE 4. NEPHELOMETER AUDIT RESULTS (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

Station Number Location, Organization	Nephelometer Model	Audit Parameter	Meter Range Units	Audit Input	Meter Response	Difference Audit - Meter		Regression of Motor Response on Audit Input - Y = mX + b		
						ppm	percent	Slope	Intercept	Correlation Coefficient
Mobile Station R-28	MRI Model 1561	Scattering Coefficient	0 to 10 b scat	0.00	0.07	0.07	--	1.1527	0.070	1.0000
Radian	S/N 122		10^{-4} m^{-1}	4.06	4.75	0.69	17.0			
Mobile Station	MRI Model 1561	Scattering Coefficient	0 to 10 b scat	0.00	-0.02	-0.02	--	1.0958	-0.020	1.0000
EPA/IPAB	S/N 114		10^{-4} m^{-1}	4.07	4.44	0.37	9.1			

Source: Pasquini, Murdoch, Michie, Sexton[14]

TABLE 5. HIGH VOLUME SAMPLER AUDIT RESULTS (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

Station Number, Location Organization	Sampler Model and S/N	Audit Parameter	Audit Flow Rate ACFM	Sampler Flow Rate ACFM	Difference Audit - Sampler		Mean Percent Difference ± Std Deviation Audit - Sampler
					ACFM	Percent	
Mobile Station K-28 Radian	High Volume S/N 12510	Flow Rate	26.5	27.0	0.5	1.9	-0.50 ± 2.07
			33.1	33.5	0.4	1.2	
			39.2	39.0	-0.2	- 0.5	
			45.7	44.5	-0.2	- 2.6	
			48.7	47.5	-1.2	- 2.5	
	High Volume S/N 11900	Flow Rate	26.5	29.0	2.5	9.4	1.22 ± 5.23
			33.1	34.0	0.9	2.7	
			39.4	39.5	0.1	0.3	
			43.5	42.5	-0.1	- 2.3	
			47.4	45.5	-1.9	- 4.0	

Source: Pasquini, Murdoch, Michie, Sexton [14]

TABLE 6. METEOROLOGICAL SENSOR AUDIT RESULTS (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

Station Number, Location, Organization	Audit Parameter	Sensor Units	Audit Level	Sensor Response	Difference Audit - Sensor	
					Unit	Percent
Mobile Station R-28 Radian	Wind Speed			Operational		
	Wind Direction	Degrees	2	2	6.5[a]	NA
	Temperature	Celsius	29.5	29.8	0.3	1.0
	Dew Point	Celsius	18.9	18.1	- 0.8	- 4.2

[a] Area declination approximately -6.5°W.

NA - Not applicable.

Source: Pasquini, Murdock, Michie, Sexton[14]

TABLE 7. AUDIT RESULTS OF EAA IN AQML

Total flow (measured)	48.4 liter/min
Total flow (specification)	50.0 liter/min
Aerosol flow (measured)	4.0 liter/min
Aerosol flow (specification)	4.0 liter/min

Error in Indicated Voltage (EAA DVM):

Less than 0.002 volts over the range of 0.0 to 3.0 volts

Ionizer current/ionizer voltage ratio = 0.80 (manufacturer specification = 1.10 ±0.16)

Source: Personal communication from Larry Cupitt, Northrop Services, Inc. 1979 probably valid when ion current within specs." It is noteworthy that the ion current was measured and recorded on a daily basis, and only fell below the specified value during periods of high humidity.

The optical particle counters (OPC) in both the AQML and R-28 were audited on 9/28/78 for the AQML and on 9/30/78 for R-28. Dow Diagnostics spheres of six sizes in the size range 0.36 to 3.7 microns were used. Flow rates were also checked. For the AQML the actual flow rate was 6.7 liter/min (versus a specification of 7.0 liter/min). The auditor's comment regarding particle size measurement was "This system seems to attenuate the two smallest channels. Data for particles larger than 0.42 microns looks good." It should be noted that this problem was recognized earlier, and, during the data analysis, data for the two smallest channels were only used to indicate trends. For R-28 the actual flow rate was found to be 7.0 liter/min (with a specification of 7.0 liter/min). The auditor's comments on the particle size measurement were "The OPC seems to have been calibrated correctly at the 2.02 micron setting. Modes on all other sizes seem about one bin low. It would appear that, on the average, results on this OPC should be shifted one bin higher."

Based on these audit results, inferences can be drawn regarding the uncertainty in the data reported in this document. These estimated uncertainties are presented below. For those parameters which had multi-point audits, the 95% confidence limits are given. For the others, a percentage of indicated value is given. These values are approximate only since the sample size is too small to provide statistically significant estimates.

STATION	MEAN % OF DIFFERENCE	STANDARD DEVIATION	95% CONFIDENCE LIMITS UPPER	LOWER
R-28 (ozone)	3.34	5.37	13.8	-7.2
R-28 (NO)	0.04	2.99	5.9	-5.8
R-28 (NO_x)	0.86	4.44	9.6	-7.8
R-28 (SO_2)	-15.72	3.33	-9.2	-22.2
AQML (ozone)	4.80	7.94	20.4	-10.8
AQML (ozone)(uv)	-3.13	7.83	12.2	-18.5
AQML (NO)	-1.48	2.99	4.4	-7.3
AQML (NO_x)	0.92	1.69	4.2	-2.4
AQML (CO)	-37.76	28.07	17.3	-92.8
R-28 (hivol)	-0.50	2.07	3.6	-4.6
R-28 (hivol)	1.22	5.23	11.5	-9.0

STATION	INSTRUMENT	ESTIMATED UNCERTAINTY
R-28	Nephelometer	20%
AQML	Nephelometer	15%
R-28	Temperature	1°F
R-28	Dew Point	2°F
R-28	Electrical Aerosol Analyzer	±25%
AQML	Electrical Aerosol Analyzer	±25%
R-28	Optical Partical Counter	±25%
AQML	Optical Partical Counter	±25%

DAILY OPERATIONS PROCEDURES

Deployment of the various monitoring platforms was organized daily during afternoon planning sessions. The sessions provided feedback to the EPA field project officer as to daily activities, acquired data, specific problem areas and overall project coordination. Staff meteorologists from Radian's Austin office provided daily forecasts of wind direction and speed, cloud cover, and probability of precipitation (Figure 13). This forecast, along with the prior day's sampling results, were used to select a previously defined experiment for the upcoming day.

Field personnel were informed of any relocation of the monitoring systems. Relocation took place after 6:00 p.m. and the systems were operated by Radian personnel, except for the AQML which was operated by Environmental Measurements, Inc. (EMI) under subcontract to Radian. An experienced Radian instrument engineer assisted in AQML operations during the last half of the field sampling.

Relocatable trailer AQML instrumentation was zero/spanned on a daily basis between the hours of 5:00 and 6:00 a.m. Examples of the system operation check sheets is shown in Appendix J. Following relocation of a system, care was taken to ensure that all instrumentation was functioning properly. The wind direction transmitter was realigned with the aid of a transit. When data systems were activated, collection of data began.

FORECAST PARAMETER FORM

Forecast Parameters for HACS

Experiment Date: ______________1978

Time & Date Forecast Made __________(CDT)______________1978
for experiment day (Next Day)

WD____________a. Persistent___________b. Variable_____________
(N,NE,E,SE,S,SW,W,NW)

c. Shifting____________Cause of Shift*____________
*(e.g.,land/sea breeze, frontal passage)

WS________________mph. Remarks:______________________________

Precip. Probability____________% Type_________________________
(general, spotty)

Cloudiness: a. Fair____ b. Partly Cloudy_____ c. Cloudy_____
Remarks:____

Cloud Level(s): a. Low____ b. Middle____ c. High_____
(<6500 ft.) (6500-16,000 ft.) (>16,000 ft.)
Remarks:______________________________________

Forecast Prepared By:____________________________
Forecast Telephoned To:__________________________
By:________________ Time:____________(CDT)

Figure 13. Forecast Parameter Form (Houston Aerosol Characterization Study, 1978).

The high volume samplers and ADS units were serviced at approximately 6:00 a.m. and 6:00 p.m. daily. Sampler flow rates were recorded and the operation of the timer was checked. Daily data summaries were completed for the high volume samplers, as shown in Table 8.

Special care was taken transporting the microquartz filters to and from the field (Appendix H). The filters were wrapped in aluminum foil which had been washed in methylene chloride. Handling of the filters was kept to a minimum to prevent contamination. Once the filters were returned to the field laboratory, they were transferred to glass bottles and refrigerated. All samples were sealed in glass tubes prior to shipment to an EPA laboratory for chemical analysis.

TABLE 8. EXAMPLE OF DAILY DATA SUMMARY FOR HIGH VOLUME SAMPLES (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

DATE 282 10/9/78 Mon. (~6A-6P)

FILTER	MQ-0100	GA-0114	MQ-0101	GA-0115	GS-0001	GS-0002	MQ-00102	GA-0116
SITE	02	02	23	23	21	21	22	22
SAMPLER	01	02	03	04	05	06	07	08
FINAL WT. (g)		3.7148		3.6672	3.9968			3.6170
INITIAL WT. (g)	4.2711	3.5551	4.4279	3.5555	3.8904	3.8738	4.4112	3.5604
PART. WT. (g)		0.1597		0.1117	0.1064			0.0566
CORR. FLOW RATE (Ft³/min)	47.2	42.5	60.7	47.8	50.2	49.7	53.9	50.4
TIME START	0600	0600	0605	0605	0600	0600	0600	0600
TIME STOP	1805	1805.	1745.	1745.	2030.	2030	1810.	1810
TIME (Min)	725.	725.	700	700.	870.	870	730.	730.
VOL (M³)	968	871.	1202.	948.	1236.	1224.	1114.	1041.
Particulate (μg/M³)	—	183.	—	118.	86.1	—	—	54.4

(Blank Filters

MQ-0103
tw.: 4.3852

GA-0117
tw.: 3.6000

Bar Press 766 mmHg 30.14"
Temp 293 °K 68°F 20°C

ACF = CF/M x Time

$$M^3 = ACF \times \frac{1M^3}{35.32\ ft^3} \times \frac{BP}{760\ mmHg} \times \frac{298°K}{T°K} \bigg/ (1.0251)$$

Signed ________

SECTION 6

RESULTS AND DISCUSSION

This section, which is in five parts, presents the results of the Houston Aerosol Characterization Study. An inventory of all data obtained by this effort, as well as a summary of the results, are given first. A daily summary and description of Houston's meteorological conditions during the study period follows. Using these results, the contributions of incoming continental air, incoming maritime air, the Houston urban area and the Houston ship channel area are discussed in the third part, Source Area Characterization. Five days of data are discussed in more detail as Case Studies. The final section discusses the relationship of various measured parameters to visibility as measured by a localized light scattering coefficient (bsp) and the overall study results.

DATA SUMMARY AND INVENTORY

Continuous air quality (gases and aerosols) data, meteorological data, aerosol samples, and organic vapor samples were obtained at 12 sites in the Houston area between September 14 and October 14, 1978. Figure 14 shows the temporal distribution of each type of data and sample obtained.

Over 2000 parameter-hours of gaseous pollutant data, 1600 parameter-hours of aerosol data and over 3100 parameter-hours of meteorological data were obtained. Tables 9 and 10 list the number of hours of valid data for each parameter by site. These data are summarized in Table 11. In addition, over 480 valid upper air soundings were performed to obtain wind speed and direction up to 5000 feet above ground level. About 100 of these soundings also measured air temperatures. Table 12 provides an inventory of these soundings by site and date.

All these data have been assembled into a uniform data archive on magnetic tape for computer usage. Appendix A describes the data tape; Appendixes K through N list the continuous gas and aerosol monitoring data. These appendixes are contained in Volume 3 of this report, available from Radian Corp. The voluminous upper air meteorological data are not given here for the sake of brevity. For convenience, the data archive tape also contains upper air data from a tethersonde operated and reported by another EPA contractor.

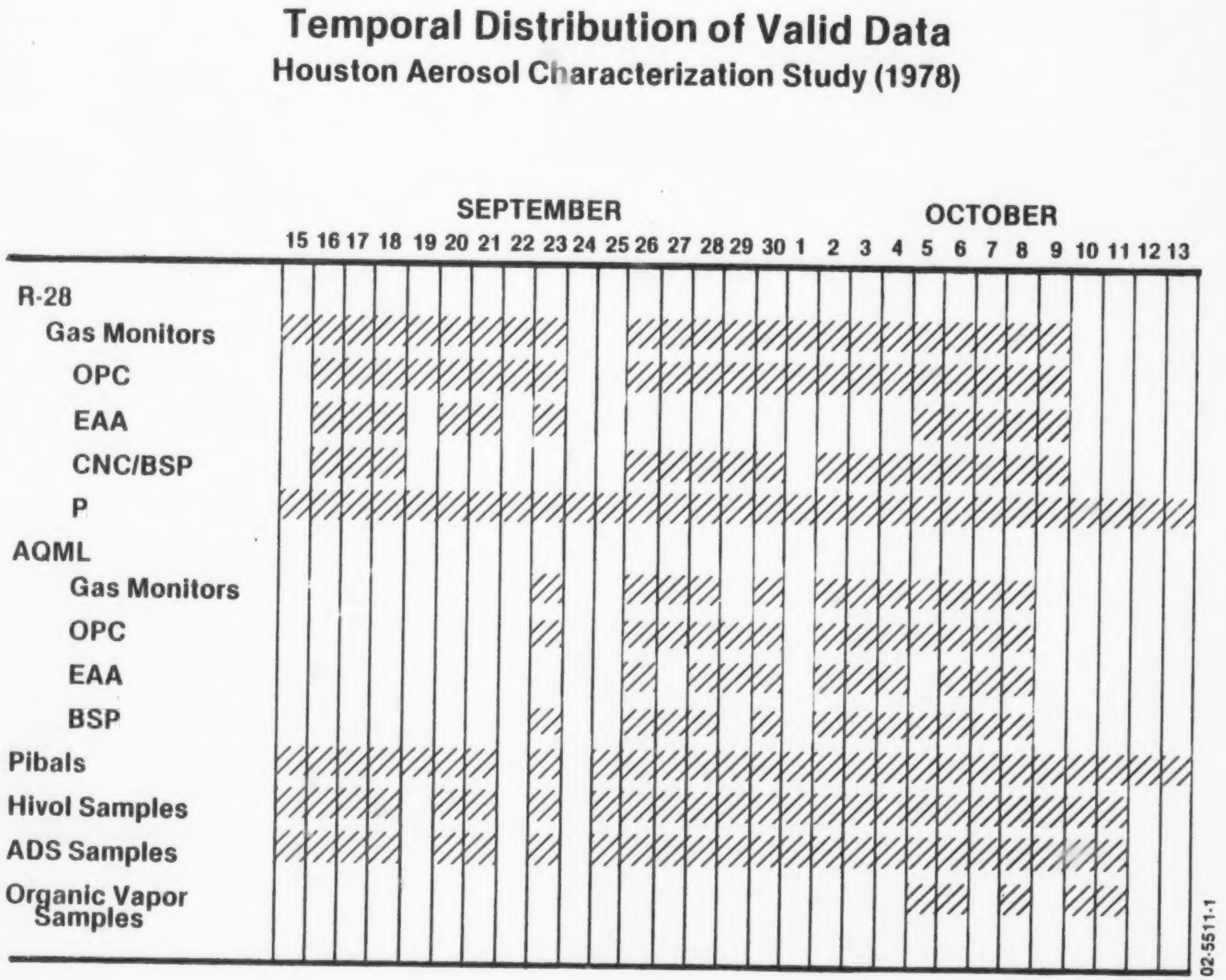


Figure 14. Temporal Distribution of Valid Data (Houston Aerosol Characterization Study, 1978).

TABLE 9. DATA INVENTORY FOR TRAILER R-28
(Hours of Valid Data)

Date	Site	O_3	NO/NO_2	SO_2	EAA	OPC	CNC	BSP	HBS	WS	WD	T	DP	TOTAL SRAD	UV SRAD	P
9/15	21(13)	12(3)	12(3)	12(3)	-	-	-	-	-	9(2)	9	8(2)	9(2)	9(2)	-	14(3)
9/16	13	23	23	23	12	13	12	0	0	24	13	24	24	24	-	24
9/17	13(19)	17(3)	17(3)	17(3)	11	13	13	0	0	18(2)	18(2)	18(2)	18(2)	18(2)	-	18(3)
9/18	19	23	23	19	13	13	14	14	0	24	24	24	24	24	-	24
9/19	19(23)	18(4)	17(4)	12(4)	-	-	-	-	-	18(4)	18(3)	18(3)	18(3)	18(4)	-	18(4)
9/20	23	24	24	24	13	13	13	13	13	24	24	24	24	24	-	23
9/21	23	17	17	17	11	12	12	13	13	18	18	18	18	18	-	24
9/22	23	12	12	12	-	-	-	-	-	12	12	12	12	12	-	24
9/23	23	11	11	11	7	8	8	8	8	12	12	12	12	14	-	24
9/24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24
9/25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24
9/26	19(23)	16	15	16	0	16	17	15	15	16	16	16	16	16	-	16(5)
9/27	19	24	23	21	0	24	20	24	24	24	24	24	16	24	-	24
9/28	19	23	23	24	0	19	13	15	18	24	24	24	23	24	-	24
9/29	19(23)	18(4)	18(4)	18(4)	0	12	13(3)	17	17	18(4)	18(4)	18(4)	11(4)	18(4)	-	18(5)
9/30	23	22	22	22	0	18	18	0	13	23	22	23	23	24	24	24
10/1	23	19	21	20	0	24	0	0	0	24	24	24	24	24	24	24
10/2	23(17)	17(3)	17(3)	17(3)	0	18(4)	13	13	0	18(3)	18	18(3)	18(3)	21(3)	21(3)	24
10/3	17(23)	23	22	23	0	24	18	0	18	24	-	24	24	24	24	4(16)
10/4	17	23	23	23	0	20	19	1	18	24	9	24	24	24	24	24
10/5	17	22	22	22	3	24	24	24	0	23	23	23	8	24	24	24
10/6	17(21)	16(4)	16(4)	17(4)	10	18(4)	18	18	0	17(3)	17(3)	17(3)	17(3)	17(3)	17(3)	18(4)
10/7	21	23	23	23	15	24	19	18	0	24	24	24	24	24	24	24
10/8	21	23	23	23	13	24	22	22	0	24	24	24	24	24	24	24
10/9	21	17	17	17	15	19	18	18	0	18	18	18	16	18	18	24
TOTAL		464	461	454	107	364	307	233	157	478	421	478	444	483	227	577

TABLE 10. DATA INVENTORY FOR AQML TRAILER
(Hours of Valid Data)

Date	Site	O_3	NO/NO_2	SO_2	EAA	OPC	BSP
9-23-78	13	8	6	8	0	9	8
9-24-78	13	0	0	0	0	0	0
9-25-78	-	-	-	-	-	-	-
9-26-78	13	14	14	14	0	12	14
9-27-78	13	23	23	23	0	14	23
9-28-78	13	16(10)	16	16	3	3	16
9-29-78	14	0	0	0	5	10	0
9-30-78	2	6(6)	7	7	6	15	7
10-01-78	-	-	-	-	-	-	-
10-02-78	2	14(14)	14	12	14	14	14
10-03-78	20	13(13)	13	8	15	15	13
10-04-78	14	3(3)	3	3	5	8	3
10-05-78	14	21(21)	21	21	0	22	21
10-06-78	14	15(15)	14	15	4	16	16
10-07-78	22	18(18)	18	17	18	18	18
10-08-78	22	22(22)	22	22	23	23	22
10-09-78	22	16(16)	16	16	16	16	16
TOTAL		189(138)	187	182	109	195	191

NOTE: O_3 was monitored using two methods: chemiluminescent and photometric. The hours of photometric data are shown in parentheses above.

TABLE 11. DATA SUMMARY FOR THE HOUSTON AEROSOL CHARACTERIZATION STUDY (1978)

Parameter (Units)	Relocatable Trailer, R-28 Number of Hours	Range of Hourly Averages	Average	Mobile Laboratory, AQML Number of Hours	Range of Hourly Averages	Average
O_3 (µg/m^3)	464	0-254	48	189 (138)	0-221 (0-197)	80 (64)
NO (µg/m^3)	461	0-768	51	187	0-646	32
NO_2 (µg/m^3)	461	0-182	38	187	0-140	34
SO_2 (µg/m^3)	454	0-191	7	182	0-63	4
CNC (#/cm^3)	307	0.7 - 23.8	6.5	N/A	N/A	N/A
BSP ($10^{-4}m^{-1}$)	233	0.1 - 4.2	1.5	191	0.2 - 5.5	2.0
HBS ($10^{-4}m^{-1}$)	157	0.2 - 3.3	1.6	N/A	N/A	N/A
Wind Speed (mph)	478	0-15	5	N/A	N/A	N/A
Temperature (°F)	478	59-93	75	N/A	N/A	N/A
Dew Point (°F)	444	41-76	66	N/A	N/A	N/A
SRAD (Langleys)[2]	483	152-504	347	N/A	N/A	N/A
UV Solar Rad (Langleys)[2]	227	8.8 - 20.6	17.1	N/A	N/A	N/A

[1] O_3 measured with chemiluminescent method except for values in parentheses which use photometric method.

[2] Total radiation per day

TABLE 12. PIBAL DATA INVENTORY (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)(Number of Valid Observations)

	Site 17		Site 24	
Date	Upper Air	Temperature	Upper Air	Temperature
9-15	9	2	9	2
9-16	10	2	10	2
9-17	10	2	9	2
9-18	10	2	10	2
9-19	9	2	10	2
9-20	8	2	8	2
9-21	7	2	6	1
9-22				
9-23	5	2	0	1
9-24				
9-25	10	2	8	1
9-26	9	2	10	2
9-27	10	2	9	2
9-28	8	2	10	2
9-29	10	2	9	2
9-30	10	2	10	2
10-01	10	2	10	2
10-02	10	2	10	2
10-03	5	0	10	2
10-04	10	2	10	2
10-05	10	2	9	2
10-06	8	1	7	2
10-07	10	2	10	2
10-08	8	2	10	1
10-09	10	1	9	2
10-10	8	1	10	1
10-11	9	2	10	1
10-12	10	2	9	2
10-13	9	2	7	2
Total	242	49	239	48

Aerosol and gas samples were obtained for gravimetric and chemical analyses. Total suspended particulate concentrations were determined using high volume samplers. A total of 89 twelve-hour samples were obtained during the study period. These data are given in Table 13. The average particulate loading was 95 $\mu g/m^3$ with a range from 21 $\mu g/m^3$ to 250 $\mu g/m^3$. Simultaneously, a similar number of high volume samples for organic analysis by EPA-designated contractors was obtained on quartz filters.

Over 100 pairs of size-fractionated aerosol samples were collected using virtual dichotomous samplers. An inventory of these samples is given in Table 14. XRF analysis of these filters was performed by EPA and the results reported elsewhere. Finally nine organic vapor samples (Table 15) were obtained for organic analysis by an EPA-designated contractor.

On twelve days, coincident upwind-downwind sampling was performed using two relocatable monitoring trailers and up to five virtual dichotomous samplers, eight hi-vols, and two pibal sites. The data collected are summarized for each similar field sampling array in Figures 15 through 20.

PREVAILING METEOROLOGY DURING THE STUDY PERIOD

This section is a day-by-day synopsis of general weather conditions over the Houston area during the period September 15 - October 9, 1978. National Weather Service data as well as meteorological data from the current study were used for these weather descriptions. Large scale and mesoscale flow characteristics, sky conditions, temperature ranges, and precipitation activity are briefly described.

Large scale flow conditions do not always represent actual surface wind direction and wind speed conditions over the Houston area. When the large scale flow is strong, it generally closely represents actual wind directions and speeds over the area; however, under weak large scale flow conditions, wind directions and speeds can vary significantly, both on a spatial and temporal basis. The best example of this variation is the land/sea breeze regime, which is sometimes present in the Houston area.

The land/sea breeze effect in the Houston area is most easily detected when the synoptic pressure gradient is very weak. As the land becomes cooler than the nearby Gulf of Mexico during the night, a pressure gradient is created such that a land-to-sea component is added to the large scale flow. In the Houston area, the land breeze tends to show up as a light northeasterly flow during the night and early morning. During the day, when

TABLE 13. TOTAL SUSPENDED PARTICULATE SUMMARY ($\mu g/m^3$)(HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

		Site Number											
Date	Time Period	1	2	12	13	14	17	19	20	21	22	23	
9/15	6AM - 6PM	75	74							54			
9/16	6AM - 6PM	43	64		69								
	6PM - 6AM	46	42	21	38								
9/17	6AM - 6PM		48	27									
9/18	6AM - 6PM	52	117			65		68					
9/20	6AM - 6PM					62		52				98	
9/21	6AM - 6PM											94	
9/23	6AM - 6PM	82	152		78							98	
9/25	6AM - 6PM	114	224									112	
9/26	6AM - 6PM	127			60					123			
	6PM - 6AM	88			58			125		85			
9/27	6AM - 6PM	144			64			183		125			
	6PM - 6AM	57			41			70		51			
9/28	6AM - 6PM	78			68			103		87			
9/29	6AM - 6PM	94						105	43			71	
9/30	6AM - 6PM	70	136					75				70	
10/2	6AM - 6PM	141	244					105				132	
10/3	6AM - 6PM	133	250				95		88				
10/4	6AM - 6PM	113					97		92				
10/5	6AM - 6PM	108	238			109	91						
10/6	6AM - 6PM			88			132		65				
10/7	6AM - 6PM	53							52	71		99	
10/8	6AM - 6PM	157									67	120	
10/9	6AM - 6PM		183							86	54	118	
10/10	6AM - 6PM		222								63	149	
	6PM - 6AM										31		
10/11	6AM - 6PM										66	91	
													Total
Number of Samples		19	13	3	8	3	4	9	5	8	5	12	89
Mean		93	153	45	59	78	104	98	68	85	56	104	95

TABLE 14. INVENTORY OF AUTOMATIC DICHOTOMOUS SAMPLES COLLECTED FOR ANALYSIS BY EPA (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

DATE	TIME	SITES
9/15	6AM - 6PM	1, 2, 21*
9/16	6AM - 6PM	1, 2, 13*
9/16-17	6PM - 6AM	1, 2, 13*
9/17	6AM - 6PM	1, 2, 13*
9/18	6AM - 6PM	1, 2, 19*
9/20	6AM - 6PM	1, 2, 23*
9/21	6AM - 6PM	1, 2, 23*
9/23	6AM - 6PM	1, 2, 23*
9/25	6AM - 6PM	1, 2, 23*
9/26	6AM - 6PM	1, 2, 13, 19*
9/26-27	6PM - 6AM	1, 2, 13, 19*
9/27	6AM - 6PM	1, 2, 13, 19*
9/28	6AM - 6PM	1, 2, 13, 19*
9/29	6AM - 6PM	1, 2, 14, 19*
9/30	6AM - 6PM	1, 2*, 23*
10/2	6AM - 6PM	1, 2*, 23*
10/3	6AM - 6PM	1, 2, 17*, 20
10/4	6AM - 6PM	1, 2, 14, 17*
10/5	6AM - 6PM	1, 2, 14, 17*
10/6	6AM - 6PM	1, 2, 14, 17*
10/7	6AM - 6PM	1, 2, 21*, 23
10/8	6AM - 6PM	1, 2, 21*, 22
10/9	6AM - 6PM	1, 2, 21*, 22
10/10	6AM - 6PM	1, 2, 21*, 22

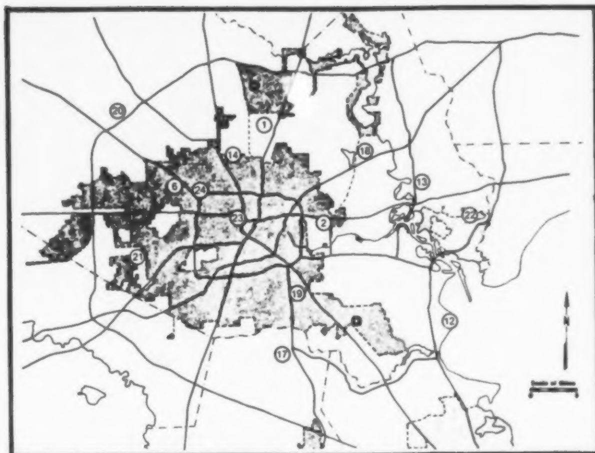
*Two samplers operated simultaneously at this date and site.

Total Number of Samples: 111

TABLE 15. INVENTORY OF SAMPLES COLLECTED FOR ORGANIC VAPOR ANALYSIS FOR EPA (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

Date	Time	Site(s)
10/5-6	6PM - 6AM	23
10/6	6AM - 6PM	23
10/8	6AM - 6PM	21
10/10	6AM - 6PM	21, 22
10/10-11	6PM - 6AM	22, 23
10/11	6AM - 6PM	22, 23

Total Number of Samples: 9



Houston Aerosol Characterization Study

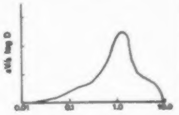
Field Sampling Array for: 9/23

Meteorological Data at Site 23

Parameter	9/23		
Avg. Wind Speed (mph)	5		
Avg. Wind Direction	NE		
Avg. Temperature (°F)	73		
Avg. Rel. Humidity (%)	81		
Total UV (langleys)	-		

Site ○	13*	23*				
Parameter						
O_3 Maximum[1]	96	76				
Time[2]**(CST)**	1400	1300				
NO Average[1]	2	9				
Maximum[1]	3	14				
NO_2 Average[1]	5	22				
Maximum[1]	12	34				
SO_2 Average[1]	0	0				
Maximum[1]	0	0				
CNC Average[3]	-	4.8				
Maximum[3]	-	6.6				
b_{scat} ($10^{-4}m^{-1}$) (ambient)						
Average	3.1	3.0				
Maximum	3.4	3.2				
b_{scat} ($10^{-4}m^{-1}$) (heated)						
Average	-	2.1				
Maximum	-	2.4				

Volume Size Distribution
$\Delta V/\Delta \log D$ ($\mu m^3/cc$) vs. D (μm)

Site / Date	13	23
9/23		

Total Suspended Particulates ($\mu g/m^3$) ☐

Site	1	2	13	23		
9/23	82	152	78	98		

NOTES:

[1] **ug/m³**

[2] **Time at end of hour**

[3] **Number of particles × 10^4 per cc**

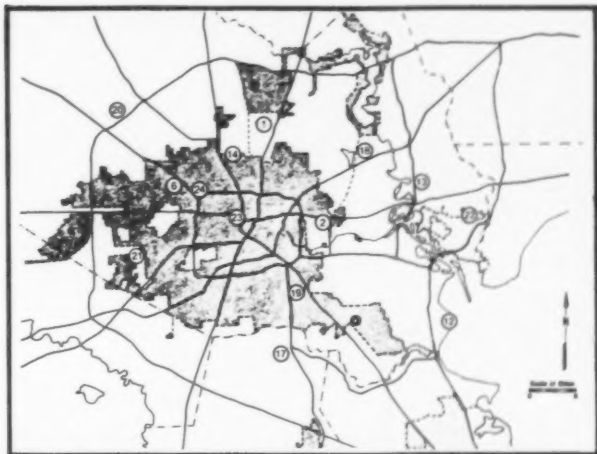
*Partial data set

02-5510-1

Figure 15. Field Sampling Array for September 23, (Houston Aerosol Characterization Study, 1978).

Houston Aerosol Characterization Study

Field Sampling Array for: 9/26, 27, 28

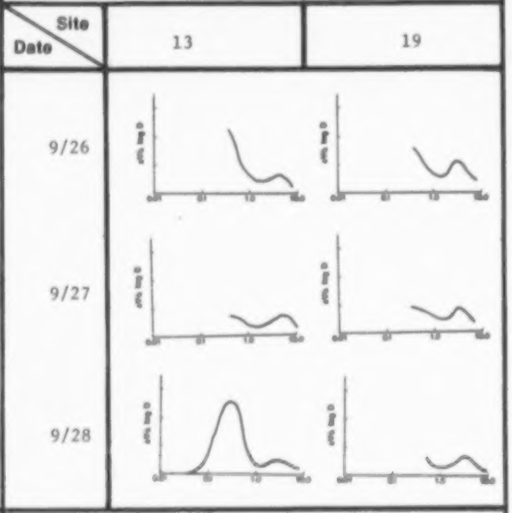


Meteorological Data at Site 19

Parameter	26	27	28
Avg. Wind Speed (mph)	6	9	7
Avg. Wind Direction	NE	NNE	NNE
Avg. Temperature (°F)	79	75	72
Avg. Rel. Humidity (%)	72	77	81
Total UV (langleys)	-	-	-

Site ○	13	19	13	19	13	19
Parameter	9/26		9/27		9/28	
O_3 Maximum[1]	137	254	163	144	97	119
Time[2](CST)	1700	1400	1500	1500	1700	1700
NO Average[1]	1	1	1	1	1	2
Maximum[1]	3	6	2	13	1	31
NO_2 Average[1]	9	48	8	33	9	37
Maximum[1]	16	83	12	91	11	81
SO_2 Average[1]	0	34	0	28	0	42
Maximum[1]	0	158	0	91	0	126
CNC Average[3]	-	7.9	-	7.1	-	8.7
Maximum[3]	-	11.7	-	12.7	-	12.6
b_{scat} ($10^{-4}m^{-1}$) (ambient) Average	3.0	3.1	2.7	2.9	2.2	1.8
Maximum	3.3	4.2	3.3	4.2	2.6	3.0
b_{scat} ($10^{-4}m^{-1}$) (heated) Average	-	2.5	-	2.3	-	4.5
Maximum	-	3.3	-	3.3	-	2.1

Volume Size Distribution
$\Delta V/\Delta \log D$ ($\mu m^3/cc$) vs. D (μm)



NOTES:

[1] ug/m³

[2] Time at end of hour

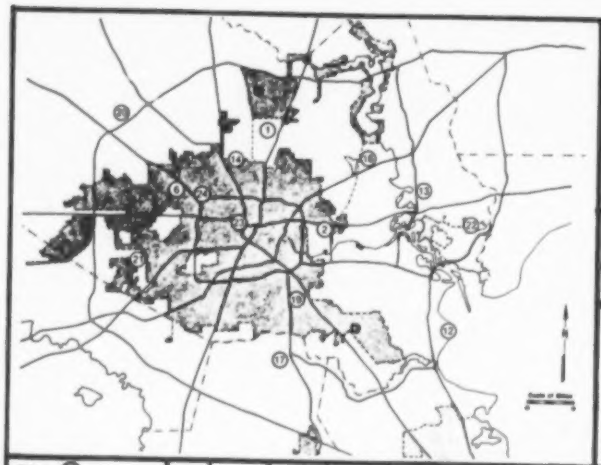
[3] Number of particles × 10⁴ per cc

Total Suspended Particulates (µg/m³) ☐

Site	9/26	9/26N	9/27	9/27N	9/28	
1	127	88	144	57	78	
13	60	58	64	41	68	
19	-	125	183	70	103	
31	123	85	125	57	87	

02-5510-1

Figure 16. Field Sampling Array for September 26, 27, and 28, (Houston Aerosol Characterization Study, 1978).



Houston Aerosol Characterization Study

Field Sampling Array for: 9/30, 10/2

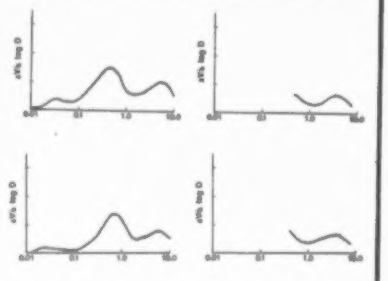
Meteorological Data at Site 23

Parameter	9/30	10/1	10/2
Avg. Wind Speed (mph)	2	CALM	CALM
Avg. Wind Direction	N	VAR	VAR
Avg. Temperature (°F)	76	77	77
Avg. Rel. Humidity (%)	78	75	78
Total UV (langleys)	20.0	17.7	17.7

Site ○	2*	23	2	2	23	
Parameter	9/30		10/1		10/2	
O_3 Maximum[1]	-	138	-	98*	217	228
Time[2](CST)	-	1400	-	1900	1300	1500
NO Average[1]	101	118	-	181	134	97
Maximum[1]	182	330	-	430	646	768
NO_2 Average[1]	45	46	-	59	65	86
Maximum[1]	62	97	-	133	119	182
SO_2 Average[1]	20	0	-	12	14	0
Maximum[1]	46	0	-	73	63	0
CNC Average[3]	-	6.0	-	-	-	11.1
Maximum[3]	-	9.9	-	-	-	16.1
b_{scat} ($10^{-4}m^{-1}$) (ambient) Average	2.2	-	-	-	2.1	2.2
Maximum	3.2	-	-	-	3.3	3.3
b_{scat} ($10^{-4}m^{-1}$) (heated) Average	-	1.3	-	-	-	-
Maximum	-	2.7	-	-	-	-

Volume Size Distribution
ΔV/Δlog D (μm³/cc) vs. D (μm)

Date \ Site	2	23
9/30		
10/2		



Total Suspended Particulates (μg/m³) ☐

Site	1	2	19	23		
9/30	70	136	75	70		
10/2	141	244	105	132		

NOTES:

[1] ug/m³

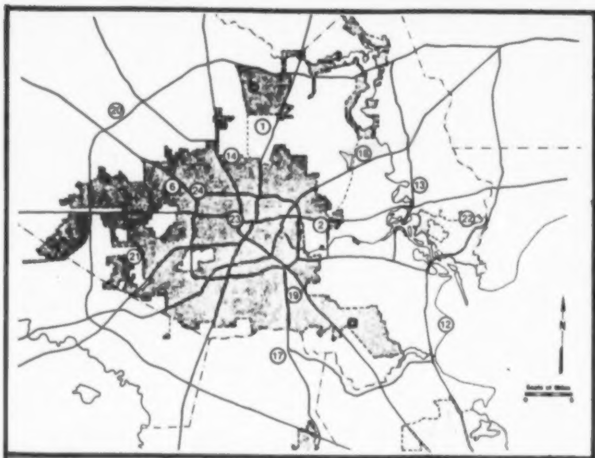
[2] Time at end of hour

[3] Number of particles × 10^4 per cc

*Partial data set

02-5510-1

Figure 17. Field Sampling Array for September 30 and October 2, (Houston Aerosol Characterization Study, 1978).



Houston Aerosol Characterization Study

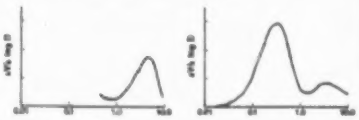
Field Sampling Array for: 10/3

Meteorological Data at Site 17			
Parameter	10/3		
Avg. Wind Speed (mph)	3		
Avg. Wind Direction	VAR		
Avg. Temperature (°F)	77		
Avg. Rel. Humidity (%)	80		
Total UV (langleys)	8.8		

Site ○	17	20				
Parameter	10/3					
O_3 Maximum[1]	107	174				
Time[2](CST)	1300	1600				
NO Average[1]	42	20				
Maximum[1]	140	64				
NO_2 Average[1]	44	59				
Maximum[1]	71	87				
SO_2 Average[1]	0	1*				
Maximum[1]	0	5				
CNC Average[3]	6.9	-				
Maximum[3]	14.1	-				
b_{scat} ($10^{-4}m^{-1}$) (ambient) Average	-	3.0				
Maximum	-	4.7				
b_{scat} ($10^{-4}m^{-1}$) (heated) Average	1.0	-				
Maximum	1.7	-				

Volume Size Distribution
$\Delta V/\Delta \log D$ ($\mu m^3/cc$) vs. D (μm)

Site / Date	17	20
10/3		



NOTES:

[1] ug/m³

[2] Time at end of hour

[3] Number of particles × 10^4 per cc

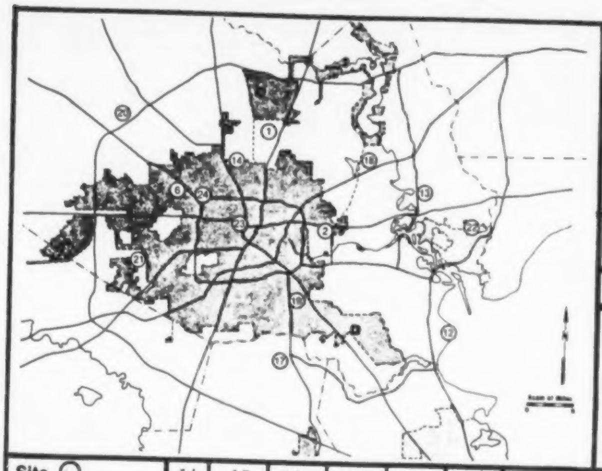
*Partial data set

Total Suspended Particulates (μg/m³) ☐

Site	1	2	17	20		
10/3	133	250	95	88		

02-5510-1

Figure 18. Field Sampling Array for October 3, (Houston Aerosol Characterization Study, 1978).



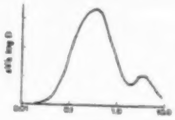
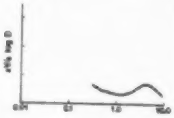
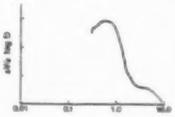
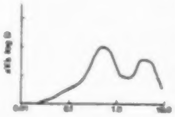
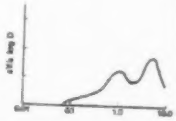
Houston Aerosol Characterization Study

Field Sampling Array
for: 10/4, 5, 6

Meteorological Data at Site 17			
Parameter	10/4	10/5	10/6
Avg. Wind Speed (mph)	5	4	6
Avg. Wind Direction	VAR	VAR	NNE
Avg. Temperature (°F)	75	77	71
Avg. Rel. Humidity (%)	80	74	67
Total UV (langleys)	19.3	16.1	12.7

Site ○	14	17	14	17	14	17
Parameter	10/4		10/5		10/6	
O_3 Maximum[1]	-	229	221	149	78	74
Time[2]**(CST)**	-	1500	1500	1600	1500	1300
NO Average[1]		45	63	36	8	21
Maximum[1]		244	191	248	36	106
NO_2 Average[1]		35	68	40	23	36
Maximum[1]		74	140	136	67	64
SO_2 Average[1]		0	8	0	0	0
Maximum[1]		6	62	0	0	0
CNC Average[3]	-	4.4	-	4.5	-	6.0
Maximum[3]	-	11.8	-	16.5	-	13.2
b_{scat} ($10^{-4}m^{-1}$) (ambient) Average	5.2	-	3.3	1.7	1.2	1.0
Maximum	5.5	-	5.5	3.0	2.7	2.6
b_{scat} ($10^{-4}m^{-1}$) (heated) Average	-	1.8	-	-	-	-
Maximum	-	2.9	-	-	-	-

Volume Size Distribution
$\Delta V/\Delta \log D$ ($\mu m^3/cc$) vs. D (μm)

Date \ **Site**	14	17
10/4		
10/5		
10/6		

NOTES:

[1] ug/m³

[2] Time at end of hour

[3] Number of particles × 10^4 per cc

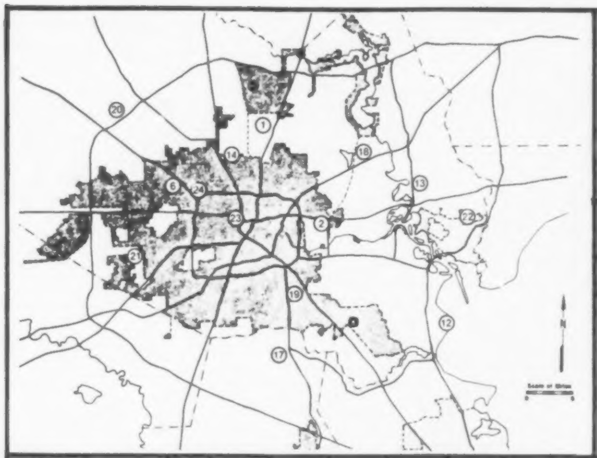
Total Suspended Particulates ($\mu g/m^3$) ☐						
Site	1	2	12	14	17	20
10/4	113	-	-	-	97	92
10/5	108	238	-	109	91	-
10/6	-	-	88	-	132	65

02-5510-1

Figure 19. Field Sampling Array for October 4, 5, and 6, (Houston Aerosol Characterization Study, 1978)

Houston Aerosol Characterization Study

Field Sampling Array for: 10/7, 8, 9

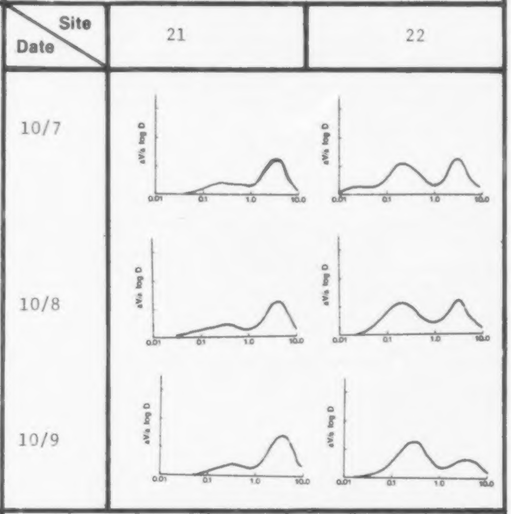


Meteorological Data at Site 21

Parameter	10/7	10/8	10/9
Avg. Wind Speed (mph)	5	7	6
Avg. Wind Direction	NE	VAR	VAR
Avg. Temperature (°F)	67	66	69
Avg. Rel. Humidity (%)	68	69	68
Total UV (langleys)	20.3	20.6	180

Site ○	21	22	21	22	21	22
Parameter	10/7		10/8		10/9	
O_3 Maximum[1]	212	182	122	147	182	132
O_3 Time[2] (CST)	1800	1600	1200	1300	1600	1700
NO Average[1]	74	30	67	27	53	7
NO Maximum[1]	220	201	342	197	225	27
NO_2 Average[1]	56	32	51	32	43	33
NO_2 Maximum[1]	143	102	113	66	103	61
SO_2 Average[1]	2	3	16	9	9	0
SO_2 Maximum[1]	30	20	191	32	70	0
CNC Average[3]	6.3	–	4.4	–	3.7	–
CNC Maximum[3]	10.6	–	9.9	–	7.6	–
b_{scat} ($10^{-4}m^{-1}$) (ambient) Average	0.6	0.6	0.6	0.8	0.8	0.8
b_{scat} ($10^{-4}m^{-1}$) (ambient) Maximum	0.9	1.3	0.9	2.5	0.9	1.5
b_{scat} ($10^{-4}m^{-1}$) (heated) Average	–	–	–	–	–	–
b_{scat} ($10^{-4}m^{-1}$) (heated) Maximum	–	–	–	–	–	–

Volume Size Distribution
ΔV/Δ log D (μm^3/cc) vs. D (μm)



Total Suspended Particulates ($\mu g/m^3$) ☐

Site	1	2	20	21	22	23
10/7	53	–	52	71	–	99
10/8	157	–	–	–	67	120
10/9	–	183	–	86	54	118

NOTES:

[1] ug/m3

[2] Time at end of hour

[3] Number of particles × 10^4 per cc

02-5510-1

Figure 20. Field Sampling Array for October 7, 8, and 9, (Houston Aerosol Characterization Study, 1978).

the land becomes warmer than the water, a pressure gradient is created such that a sea-to-land component is added to the synoptic flow. The land-to-sea component, or sea breeze, is first evident near the coastline, penetrating inland during the day. As this occurs, wind directions typically rotate clockwise from north-northeasterly around to southeasterly. The distance that the sea breeze penetrates inland varies from one case to another. Sea breezes have been observed to penetrate as far as Houston Intercontinental Airport, which is about 50 miles inland. The land/sea breeze regime undoubtedly has a significant effect on the transport and dispersion of atmospheric pollutants in the Houston area. These effects have not been studied in detail and a detailed study might produce much valuable information on pollution problems in the Houston area.

Daily Weather Synopsis (Sept. 15 - Oct. 9, 1978)

September 15--

A light, generally southeasterly large scale flow (with non-persistent mesoscale flows) brought warm, moist air into the Houston area. Skies were generally partly cloudy and a few scattered afternoon showers and thundershowers occurred. Temperatures ranged from the low 70's to the low 90's over the area.

September 16--

Warm moist air continued to flow into the area from the Gulf. The large scale flow over the area was light and generally southerly, although rather non-persistent mesoscale flows occurred. Skies were generally partly cloudy, and there were a few scattered afternoon showers. Temperatures ranged from the low 70's to the low 90's.

September 17--

The large scale flow became southeasterly over the Houston area, and strenghtened somewhat, producing slightly higher wind speeds than on the previous two days and more persistence in wind direction. Skies were again generally partly cloudy, and temperatures ranged from the low 70's to the low 90's. A few isolated, very light, daytime showers occurred.

September 18--

Weather conditions on the 18th were very similar to those on the 17th. Sunny skies, warm temperatures, a rather persistent southeasterly to south-southeasterly flow of moderate strength, and a few light showers chacterized the weather. Temperatures ranged from the mid 70's to the mid 90's over the Houston area.

September 19--

The large scale flow became more east-southeasterly over the Houston area and winds were fairly persistent. Skies continued to be sunny, with temperatures ranging from the mid 70's to the low 90's. A few light daytime showers were evident over the area.

September 20--

On the 20th, the large scale flow weakened significantly and became generally easterly. Mesoscale flows were rather non-persistent. Skies were partly cloudy to cloudy, and temperatures ranged from the low 70's to near 90. Scattered light-to-moderate afternoon showers and thundershowers occurred over the area.

September 21--

The large scale flow was generally light and northeasterly on the 21st while mesoscale flows were fairly non-persistent. Skies were partly cloudy to cloudy, and temperatures ranged from the low 70's to the upper 80's. Scattered light-to-moderate afternoon showers and thundershowers again occurred over the area.

September 22--

With the passage of a cool frontal system, the large scale flow over the Houston area became northeasterly and strengthened considerably. Winds were more persistent over the area than on the previous two days. Skies were partly cloudy, and temperatures ranged from the low 70's to near 90.

September 23--

The large scale flow over the Houston area continued to be moderate and northeasterly as a ridge of high pressure extended into Texas from the northeast. Winds were rather persistent. Skies were cloudy and very hazy. Temperatures ranged from the low 70's to the mid 80's.

September 24--

A moderate, rather persistent northeasterly flow continued over the Houston area. Skies were partly cloudy and much less hazy than on the 23rd. Temperatures ranged from the mid 60's to the mid 80's.

September 25--

A ridge of high pressure extending southward into Texas from the northern Midwest changed the large scale flow more to the north-northeast, weakened the gradient, and caused mesoscale winds to be less persistent. Skies were sunny, and temperatures ranged from the upper 50's to the mid 80's over the Houston area.

September 26--

The Houston area continued to be under the influence of a ridge of high pressure, which resulted in a light north-northeasterly flow. Winds were fairly persistent, however. Skies were cloudy and temperatures ranged from the mid 60's to the mid 90's over the area.

September 27--

The north-northeasterly flow strengthened somewhat as a trough of low pressure formed in the Gulf of Mexico off the Upper Texas Coast. Winds were rather persistent over the area. Sporadic, very light rain occurred late in the day as a result of the low pressure trough. Skies were cloudy, and temperatures ranged from the upper 60's to the mid 80's.

September 28--

The north-northeasterly flow which had prevailed over the area for several days, weakened again, and mesoscale winds were less persistent than on the previous day. Very light rain occurred during the early morning hours due to the trough of low pressure which formed in the Gulf on the 27th. Skies remained cloudy on the 28th, and temperatures ranged from the 60's to the upper 70's.

September 29--

The large scale flow over the area became more northerly as the orientation of the trough in the Gulf shifted. Wind speeds continued to be light, and mesoscale winds were fairly non-persistent. Skies were partly cloudy over the area, and temperatures ranged from the mid 60's to the mid 80's.

September 30--

As the trough of low pressure in the Gulf shifted eastward, the weak northerly flow continued. Mesoscale winds were non-persistent. Abundant sunshine prevailed, and temperatures ranged from the mid 60's to the upper 80's.

October 1--

Because the large scale flow was very weak, the land/sea breeze regime primarily controlled winds in the Houston area on the 1st. Very light winds of a northerly component prevailed during the nighttime and early morning hours. By late afternoon, when a light sea breeze had moved inland, winds were light east-southeasterly to southerly over most of the area. Skies were clear, and temperatures ranged from the low 60's to the upper 80's.

October 2--

The large scale flow remained very weak and the land/sea breeze regime may have influenced speeds and directions in the Houston area. Mesoscale winds continued to be non-persistent. Skies remained very sunny, and temperatures ranged from the low 60's to the upper 80's.

October 3--

A trough of low pressure along the Texas coast created a weak northeasterly large scale flow over the Houston area until the afternoon, when a shift in the trough's position caused flow to turn to the southeast. Skies were cloudy, and temperatures ranged from the mid 60's to the 80's.

October 4--

As a high pressure system moved eastward from the Southern Plains into the lower Mississippi Valley, the large scale flow varied from light northeasterly during the nighttime and early morning hours to light southeasterly during the afternoon. Skies were very sunny on the 4th, and temperatures ranged from the mid 60's to the mid 80's.

October 5--

The large scale flow was very weak on the 5th; the land/sea breeze regime probably had a major influence on wind speeds and directions. Mesoscale winds were non-persistent. Skies were partly cloudy, and temperatures ranged from the mid 60's to the low 90's over the Houston area.

October 6--

A cool front passed through the Houston area during the morning, resulting in a moderate north-northeasterly flow and cloudy skies. Winds were much more persistent than on the previous several days. Temperatures cooled significantly, ranging from the upper 50's to the upper 70's.

October 7--

A ridge of high pressure extending southward into East Texas from the northern Midwest resulted in a light north-northeasterly flow until the afternoon, when the ridge had changed orientation. The change in orientation caused a shift of the flow to light east-northeasterly. Skies were partly cloudy, and temperatures ranged from the mid 50's to the upper 70's over the area.

October 8--

The Houston area continued to be under the influence of a high pressure ridge. The large scale flow varied from light northeasterly during the night and morning to moderate-to-strong east-southeasterly during the afternoon. Skies were partly cloudy, and temperatures ranged from the low 50's to the 70's.

October 9--

Weather conditions were similar to those on the 8th, except that sunshine was more abundant on the 9th. The large scale flow again varied from light northeasterly during the night and morning to light-to-moderate east-southeasterly during the afternoon. A sea breeze effect may have helped to increase winds during the afternoon in southern parts of the area. Temperatures ranged from the low 50's to the low 80's.

Dispersion Conditions During the Study Period

A simple scheme was used to qualitatively estimate peak daytime dispersion conditions in the Houston area during the study period. The classification scheme is based only on peak daytime sustained winds and the average amount of cloud cover from sunrise to sunset. Mixing heights* and transport wind speeds,** the use of which offers a more reliable estimate of dispersion conditions, were not calculated for this effort. However, the method used gives a good indication of relative peak dispersion conditions over the study period.

The peak sustained wind (peak one-minute average) was chosen as a factor in estimating peak dispersion conditions since it is an indicator of the strength of the transport wind speed at a time when mixing is strongest in the mixing layer. The peak sustained wind speed from the National Weather Service at Houston Intercontinental Airport was used in the dispersion estimates. The average amount of cloud cover (in tenths) from sunrise to sunset was also obtained from Intercontinental Airport. The amount of cloud cover is one indicator of the amount of thermal mixing which can take place in the mixing layer. For example, if the average cloud cover from sunrise to sunset were only three tenths, one would expect more thermal mixing (and better dispersion) than if the average cloud cover were eight tenths, all other variables remaining the same. The use of meteorological data from one particular location in the Houston area may result in dispersion estimates that are not representative of the entire area.

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*Mixing height is defined as the height above the surface to which turbulence (mechanical and thermal) causes the air to be well mixed.

**Transport wind speed is the average wind speed in the mixed layer of the atmosphere between the surface and the mixing height.

Table 16 summarizes the classification scheme used for the estimates of peak daytime dispersion conditions. Dispersion is considered poor if the peak sustained wind speed is 0 - 10 mph, fair if it is 11 - 15 mph, and good if it is greater than 15 mph. Each of the three major classes - poor, fair, and good - is broken down further according to the average cloud cover from sunrise to sunset. The classification scheme is set up such that peak dispersion conditions improve with an increase in peak sustained wind speed and a decrease in average cloud cover. There are nine categories, ranked from one to nine in order of improvement in peak dispersion conditions.

Table 17 shows the daily peak sustained wind speed, average cloud cover from sunrise to sunset, the occurrence of significant rain or thunderstorms, and the peak dispersion category for the study period. If significant rain (greater than 0.25 inch) or thunderstorms occurred over much of the area during daylight hours, the day's peak dispersion was classified as good, regardless of the peak sustained wind speed.

Based on the classification scheme devised, peak dispersion conditions were best on September 19th, 20th, 21st, 22nd, and 27th, and October 8th. The good peak dispersion conditions on all of these days except September 20th and 21st can be attributed in large part to favorable transport wind speeds. On September 20th and 21st, good peak dispersion conditions can be attributed in large part to thunderstorm activity over the Houston area.

The worst peak dispersion conditions occurred on September 26th, 28th, 29th, and 30th, and October 1st. The poor peak dispersion conditions from September 28th through 30th were due in large part to the weak, generally northerly synoptic flow resulting from a trough of low pressure in the Gulf of Mexico southeast of the Upper Texas Coast. The poor peak dispersion conditions on the 26th of September were largely the result of a

TABLE 16. PEAK DAYTIME DISPERSION CLASSIFICATION SCHEME (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

Peak Sustained Wind Speed mph	Average Cloud Cover, Sunrise to Sunset (tenths)		
	0-3	4-7	8-10
0 - 10	Poor 3	Poor 2	Poor 1
11 - 15	Fair 6	Fair 5	Fair 4
>15	Good 9	Good 8	Good 7

TABLE 17. PEAK DAYTIME DISPERSION CONDITIONS, SEPTEMBER 15 TO OCTOBER 9, 1978 (HOUSTON AEROSOL CHARACTERIZATION STUDY, 1978)

Date	Peak Sustained Daytime Wind Speed (mph)			Cloud Cover, Sunrise to Sunset (tenths)			Significant Rain or Thunderstorms		Peak Dispersion Category
	0-10	11-15	>15	0-3	4-7	8-10	Yes	No	
Sep									
15		✓			✓			✓	Fair - 5
16		✓			✓			✓	Fair - 5
17		✓			✓			✓	Fair - 5
18		✓		✓				✓	Fair - 6
19			✓	✓				✓	Good - 9
20			✓		✓		✓		Good - 8
21			✓		✓		✓		Good - 8
22			✓		✓			✓	Good - 8
23		✓			✓			✓	Fair - 5
24		✓			✓			✓	Fair - 5
25		✓			✓			✓	Fair - 5
26	✓					✓		✓	Poor - 1
27			✓			✓		✓	Good - 7
28	✓					✓		✓	Poor - 1
29	✓				✓			✓	Poor - 2
30	✓			✓					Poor - 3
Oct									
1	✓			✓				✓	Poor - 3
2		✓		✓				✓	Fair - 6
3		✓				✓		✓	Fair - 4
4		✓		✓				✓	Fair - 6
5		✓			✓			✓	Fair - 5
6		✓				✓		✓	Fair - 4
7		✓			✓			✓	Fair - 5
8			✓		✓			✓	Good 8
9		✓		✓				✓	Fair - 6

weak north-northeasterly synoptic flow resulting from a ridge of high pressure extending into Texas from the northeastern United States. Poor peak dispersion conditions on October 1st were due in large part to a very weak, ill-defined synoptic flow over southeastern Texas.

SOURCE AREA CHARACTERIZATION

A fundamental objective of the HACS program is to characterize the air quality associated with various area sources. Specifically, these sources include:

- the incoming maritime air,
- the incoming continental air,
- the urban core, and
- the industrialized ship channel.

Data collected during the 22 days of monitoring included a total of six days at three different sites downwind of the ship channel. All but one of these days represent periods of continental flow. During these periods, data were also obtained which characterized the incoming continental air and the incoming maritime air. Measurement of incoming continental air was obtained at two sites over a total of six days. Five of these days represent a single continuous period of continental flow during the early part of the study. The sixth day occurred later in the study during the passage of a minor cold front. Incoming maritime air was observed for two consecutive days at a single location during a period of southeasterly flow. A single day of stationary monitoring and one day of mobile measurements were obtained downwind of Houston's urban core during two consecutive days of variable southeasterly flow. Additionally, two consecutive days of data were obtained during a period of stagnation at a location adjacent to the ship channel and at a central urban site.

The monitoring periods selected above had relatively persistent winds, except for the monitoring period downwind of the urban core. A majority of the data obtained during the study period occurred during variable winds and, as such, has not been included in this initial analysis.

The descriptions provided below, while representative of this measurement period, should not be interpreted as statistically representative for the Houston area. The information is presented to indicate the similarities and differences in the various area sources studied.

Incoming Maritime Air

The predominant wind flow in the Houston area is from the southeast. This southeast wind carries maritime air from the Gulf of Mexico across the industrial complexes in Texas City and Bayport, and across the Galveston urban area prior to entering Houston. Thus, incoming maritime air may reflect not only natural sources of aerosols (sea salt spray), but also aerosols of anthropogenic origin from these areas. Unfortunately, no measurements were made at sites that would distinguish between the maritime background alone and the industrial emissions of the Texas City area. However, total suspended particulate (TSP) measurements were obtained at a remote coastal site (Site 12), which should not have been influenced by the industrial emissions. A comparison of the TSP values at this coastal site (Site 12) and at several inland locations south of the Houston ship channel and urban core reveals that the sites expected to reflect the transported industrial emissions of Texas City have approximately four times (4×) greater values of TSP. The TSP values at Site 12 ranged from 21 to 27 μg/m^3, while values at sites 17 and 19 ranged from 54 to 97 μg/m^3. All further references to incoming maritime air will assume the presence of an anthropogenic influence.

Visibility associated with the incoming maritime air (Site 19) was generally good. The particle scattering coefficient, as measured with the integrating nephelometer, ranged from 0.1×10^{-4} m^{-1} to 0.3×10^{-4}m^{1}. Broad maxima in bsp were evident during the midday hours that correspond to the highest periods of solar insolation. There was evidence that automobile exhaust was influencing the aerosol concentration at this location (Site 19). CNC maxima were evident at approximately 8 a.m. and 7 p.m., which corresponds to peak traffic periods. A heavily travelled freeway, as well as main highways, were within two miles of the monitoring site.

The differential volume distribution (DV/Dlog Dp) also showed the influence of automobile exhaust; i.e., a fresh combustion nuclei mode was evident in the early morning hours. The volume distribution was typically characterized by a dominant coarse particle mode, having a volume mean diameter (VMD) at approximately 4 μm diameter and geometric standard deviation (GSD) of 1.9. The coarse particle mode included 75 percent of the total aerosol volume. The accumulation mode had a VMD at 0.43 μm diameter and a GSD of 1.8. The ambient particle size (volume) distribution is commonly characterized by specific modes. The nuclei mode, when present, lies between 0.01 and 0.1 μm diameter. An accumulation mode is almost always present and ranged from 0.1 to 1.0 μm diameter. The coarse particle mode is also commonly observed and includes particles greater than 1.0 μm. The total aerosol volume tended to decrease during the day (following the morning maximum) and then increased again at the end of the day.

Ozone minima were observed to correspond to the CNC maxima during the morning peak traffic hours. The maximum ozone concentration observed was 85 $\mu g/m^3$, occurring at approximate 1600 hours. Oxides of nitrogen concentrations were low, ranging from 1 to 10 $\mu g/m^3$ throughout the day. No detectable sulfur dioxide (SO_2) was observed during this period.

Incoming Continental Air

A ridge of high pressure extending into Texas from the northeast, developed a persistent flow of continental air into the Houston area over a six day period (September 25 to September 30, 1978). The prevailing visibility was poor throughout this period, with consistent reports of smoke and haze by the National Weather Service at Intercontinental Airport. Particle scattering coefficients ranged from $4.5 \times 10^{-4} m^{-1}$ to $1.4 \times 10^{-4} m^{-1}$ with a daily average value of approximately $3.0 \times 10^{-4} m^{-1}$.

Values for TSP ranged from 43-78 $\mu g/m^3$ during this period for incoming continental air. The volume particle size distribution reveals that 80 percent of the total particle volume was contributed by the accumulation mode. The accumulation mode has a VMD approximately 0.4 μm diameter and a GSD of 1.7. The coarse particle mode VMD ranged from 1.8 μm to 5 μm diameter, averaging 3.5 μm diameter. The GSD of the coarse particle mode is 1.9.

The total aerosol volume consistently decreased during the day and increased during the evening and early morning hours. The decrease in aerosol volume occurred primarily in the accumulation mode, with the coarse particle mode changing very little throughout the day. The decrease in accumulation mode volume was found to coincide with the observed decrease in particle scattering coefficient throughout the day.

There was minimal evidence of influence by automobile exhaust, previously noted during sampling of incoming maritime air. Nitrogen dioxide (NO_2) showed slight increases at 0700 hours and 1900 hours. Values of NO_2 averaged 10 $\mu g/m^3$ during the day. Nitric oxide (NO) also increased at 0700 hours, but remained constant at 1 $\mu g/m^3$ throughout the remainder of the day. Ozone values reached daily maxima ranging from 96 $\mu g/m^3$ to 163 $\mu g/m^3$ over this period. A slight ozone depletion was observed during morning traffic hours. No sulfur dioxide was detected during the period of incoming continental air.

A second period of continental flow occurred on October 6, 1978 as a minor cold front passed through the Houston area. During this period of continental flow, visibility was much better. Values of bsp ranged from $2.2 \times 10^{-4} m^{-1}$ to $0.2 \times 10^{-4} m^{-1}$, with visibility increasing (bsp decreasing) during the day. As previously observed, this increase in visibility corresponded to a decrease in particle volume in the accumulation mode. The particle size distribution was similar to the previous period of incoming continental air, with 70 percent of the total volume contributed by the accumulation mode. The measured value for TSP was 65 $\mu g/m^3$ during this period.

The daily maximum ozone concentration was 78 $\mu g/m^3$, which is approximately half of the observed values during the earlier period of continental flow. The observed values of nitrogen oxides increased somewhat over the earlier period, with average NO values of 8 $\mu g/m^3$ and average NO_2 values of 23 $\mu g/m^3$. NO_x maxima during the morning traffic period showed a greater influence of automobile exhaust, as did the total particle number. This fact is attributed to the difference in sampling location, however, and not the incoming regional air quality.

Urban Core

Measurements of air quality downwind of Houston's urban core were confined to two days (October 3 & 4, 1978) of somewhat variable flow. This fact requires that the data be interpreted with some degree of caution. During this period visibility was poor. Values for bsp ranged from $1.5 \times 10^{-4}\ m^{-1}$ to $5.5 \times 10^{-4}\ m^{-1}$.

TSP values ranged from 65-125 $\mu g/m^3$. The differential volume distribution shows as much as 90 percent of the total aerosol volume is present in the accumulation mode, with the daily average at 85 percent. The accumulation mode VMD is approximately 0.4 μm diameter, with the GSD ranging from 1.8 to 2.5. The coarse particle mode VMD ranged from 3.8 μm to 4.4 μm diameter while the GSD was consistently 2.0. In general, the total aerosol volume was observed to decrease throughout the day, as was the particle scattering coefficient (bsp). The decrease in aerosol volume was the result of a decrease in the accumulation mode, with the coarse particle mode volume remaining constant throughout the day. Aerosol numbers showed distinct maxima in the early morning, at midday and early evening. Both aerosol and bsp showed a slight increase during the midday period, corresponding to the aerosol number concentration maxima.

Ozone values during the period reached a maximum concentration of 174 $\mu g/m^3$. Ozone depletion was observed during both the early morning hours and in the evening. Nitric oxide (NO) maxima were observed during both morning and evening traffic periods, coinciding with the ozone depletion. The observed NO maximum was 64 $\mu g/m^3$. Nitrogen dioxide showed similar maxima during morning and evening, and also at midday. These maxima coincided with the aerosol number concentration maxima previously described. The peak NO_2 value was 87 $\mu g/m^3$ with a daily average value of 59 $\mu g/m^3$.

Ship Channel

Measurements of air quality downwind of Houston's ship channel were made during periods of continental flow (September 26-29 and October, 1978) and maritime flow (September 16, 1978). Air quality downwind of the ship channel during the period of incoming continental air reflected the poor visibility associated with the upwind values previously described. Values of bsp ranged from $1 \times 10^{-4}\ m^{-1}$ to $4.2 \times 10^{-4}\ m^{-1}$. The average bsp during this four day period was $2.5 \times 10^{-4}\ m^{-1}$.

TSP values ranged from 103 $\mu g/m^3$ to 183 $\mu g/m^3$ during the hours from 6 AM to 6 PM. TSP values during the night time hours were somewhat less ranging from 70 $\mu g/m^3$ to 125 $\mu g/m^3$. The particle size distribution is not complete during this period due to a failure of the charging section of the EAA. The size distribution data are limited to the range from 0.5 μm to 10 μm diameter. The data obtained shows a consistent coarse particle mode with a VMD at 4 μm and a GSD of 1.9. The VMD of the accumulation mode probably lies between 0.3 μm and 0.5 μm with the GSD varying between 2 and 3. The accumulation mode is estimated to contribute 70 percent of the total aerosol volume.

Ozone maxima ranged from 119 μg/m to 254 μg/m during this period. Almost complete depletion of O_3 was noted during the morning traffic period, however residual O_3 was present throughout the evening and early morning hours. NO maxima coincided with the 8 a.m. O_3 depletion with very little NO present during the day. Large NO_2 maxima (58-83 $\mu g/m^3$) were observed during this period. NO_2 was observed to decrease during midday, but build up slightly into the evening. SO_2 was observed downwind of the ship channel averaging 30 $\mu g/m^3$ with daily maxima ranging from 58 $\mu g/m^3$ to 158 $\mu g/m^3$.

Aerosol number concentrations showed broad midday maxima. The aerosol volume decreased during the day in some cases and remained fairly constant in others. The accumulation mode appeared to decrease somewhat, however in many cases the coarse particle mode tended to increase during the day. Values of bsp coincided with the volume concentrations, with daily maxima occurring in the morning hours.

During the second period of continental flow (October 6, 1978), incoming air quality was somewhat better as previously described. Downwind of the ship channel values for bsp ranged from $0.3 \times 10^{-4} m^{-1}$ to $2.6 \times 10^{-4}\ m^{-1}$. The TSP value on this day was 132 $\mu g/m^3$. The volume size distribution showed an almost equal contribution of aerosol volume by the accumulation mode and coarse particle mode. The coarse particle mode VMD was 5.0 μm with a GSD of 1.9. The accumulation mode was shifted somewhat larger particle sizes with a VMD of 1.2 μm and a GSD of 1.9.

A broad aerosol number maxima was observed at midday. The aerosol volume concentration decreased slightly during the day.

The ozone maxima were 74 $\mu g/m^3$ with depletion observed in the morning and evening. NO and NO_2 averaged 35 $\mu g/m^3$ through out the day with an evening build-up noticed. SO_2 was detected, but in small concentrations ($\leq$ 1 $\mu g/m^3$).

During the period of maritime flow (September 16, 1978), visibility measurements were not obtained. The National Weather Service at Houston's Intercontinental Airport reported early morning fog, but no smoke or haze during the day. The TSP value was 69 $\mu g/m^3$ during the day and 38 $\mu g/m^3$ during the night. The volume size distribution showed a dominant coarse particle mode having a VMD of 3.5 μm and a GSD of 2.1. The coarse particle mode contained 75 percent of the total aerosol volume. The accumulation mode had a VMD of 0.3 μm and a GSD of 1.8. The total aerosol volume tended to decrease during the day, with a significant decrease noted in the coarse particle mode. Broad maxima in the aerosol number concentration were noted during midday.

An O_3 maximum of 159 $\mu g/m^3$ occurred at 1500 hours. NO and NO_2 maxima occurred in the morning and evening, corresponding to the observed O_3 depletion. Average NO and NO_2 values during the day were 23 $\mu g/m^3$ and 16 $\mu g/m^3$ respectively, with maximum values of 66 $\mu g/m^3$ and 35 $\mu g/m^3$ respectively. Detectable concentrations of SO_2 were observed during the day.

CASE STUDIES

A more detailed accounting of five specific days of monitoring follows. These case study days were chosen as examples of each of the periods previously described. In addition to the pollutant profiles, the day's meteorology, including dispersion conditions, is described.

September 18, 1978

Maritime air flowed into the Houston area on moderate, rather persistent, generally southeast to south-southeast surface winds, as evidenced by data from the Radian monitoring trailer, which was at Site 19 (Hobby). According to Table 17, peak dispersion was fair on the 18th. Little variation in wind direction occurred at the Hobby site during the day, and because of the strength of the synoptic gradient, it is likely that little variation occurred over the Houston area, except during the few isolated showers that occurred during the day. Upper level wind data from pibal runs conducted at Pearland and at the Radian Houston office show that, during the day, upper level winds (up to approximately 10,000 feet) were generally south-southeasterly to southerly, and moderate in strength. Typically, the wind direction rotated in a clockwise fashion from south-southeasterly to southerly with increasing height.

The R-28 trailer monitored the incoming maritime air on this day at Site 19. Figure 21 shows the diurnal variations of bsp, CN, and total aerosol volume observed on this day. The particle scattering coefficient (bsp) shows a broad maximum during midday. Condensation nuclei peaked at 8 a.m. and again at 7 p.m. The total aerosol volume decreased through most of the day, and began increasing in the late afternoon. The TSP value over this 12 hour period was 68 $\mu g/m^3$.

The daily average volume size distribution is shown in Figure 22. The coarse particle mode is responsible for 75 percent of the total aerosol volume. The variation in size distribution during the day (Figure 23) clearly reveals a decrease in total aerosol volume. Both the accumulation mode and the coarse particle mode volumes decrease. The bsp also decreased during the day, coinciding with the decrease in aerosol volume.

The 8 a.m. distribution exhibits a nuclei mode. This mode was only observed between 7 a.m. and 9 a.m. and is thought to be due to local effects (automobile exhausts).

The diurnal variation of gaseous pollutants is presented in Figure 24. The O_3 minima coincides with an increase in CN. Very little oxides of nitrogen were observed throughout the day.

September 27, 1978

A trough of low pressure formed in the Gulf of Mexico off the upper Texas Coast, resulting in a moderate, rather persistent generally north-northeasterly surface flow over the Houston area. Peak dispersion conditions were good on the 27th according to Table 17. The air flowing into the Houston area could be considered continental in origin, as all of the eastern third of Texas had a similar flow. As wind data from the Radian monitoring trailer (at Hobby site) show, little variation in surface wind direction occurred during the day. Because of the strength of the gradient, it is likely that little variation occurred over the Houston area. Upper level wind data from the two pibal sites showed that winds up to 5,000 or 6,000 were generally between northerly and northeasterly. Above that level winds tended to rotate counter clockwise to the southwest. For both pibal sites, the data show light wind speeds in the layer between 4,000 and 8,000 feet. Above and below the layer were moderate to strong winds. At the Radian pibal site, this layer was no longer evident after midday, while at the Pearland site, the layer still existed but was ill-defined after midday. The Pearland pibal data show that, in this light wind layer, wind directions were sometimes rather variable, while winds in the same layer at the Radian site were more persistent.

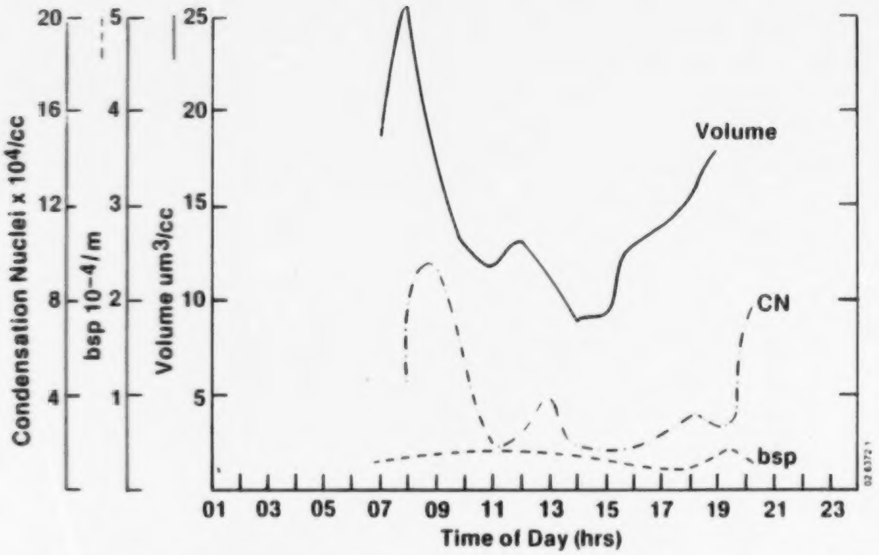


Figure 21. Diurnal Variation of Aerosol Measurements, Site 19, September 18, 1978 (Houston Aerosol Characterization Study, 1978).

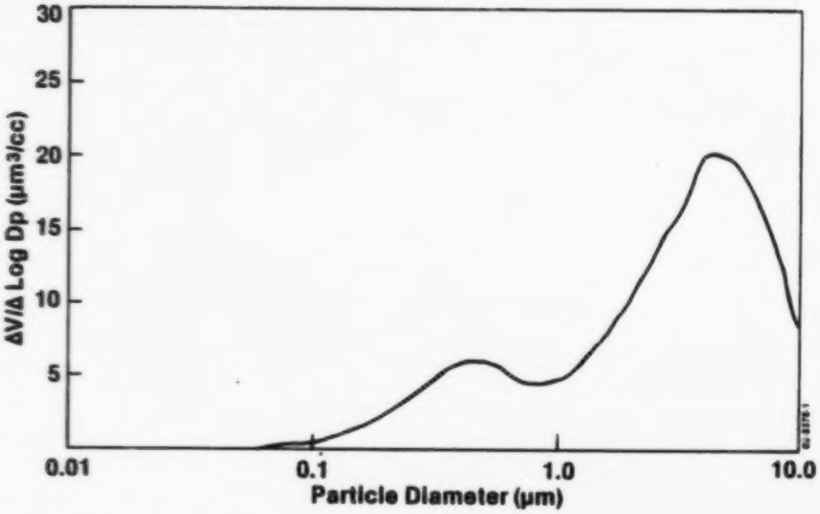


Figure 22. Daily Average Volume Distribution of Aerosols, Site 19, September 18, 1978 (Houston Aerosol Characterization Study, 1978).

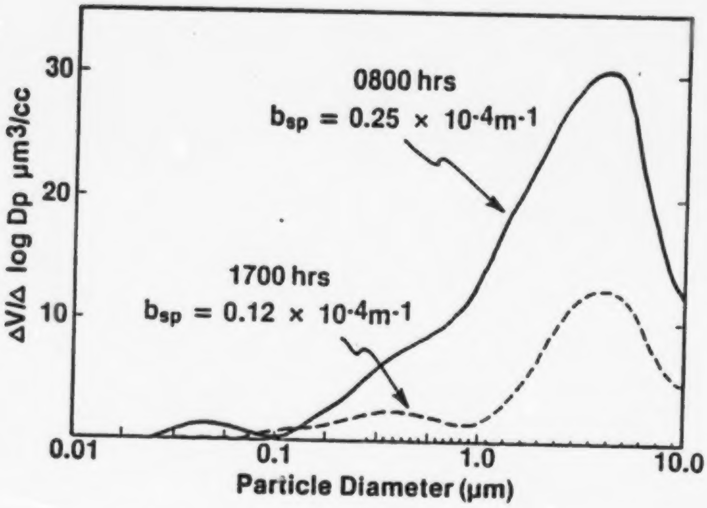


Figure 23. Volume Distribution of Aerosols, Site 19, September 18, 1978 (Houston Aerosol Characterization Study, 1978)

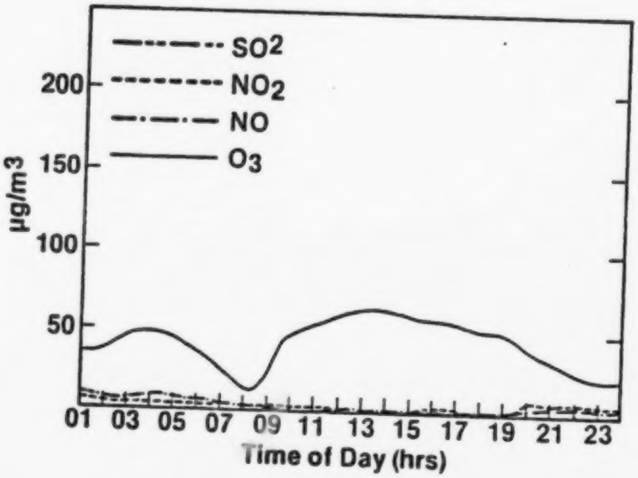


Figure 24. Diurnal Variation of Gaseous Constituents, Site 19, September 19, 1978 (Houston Aerosol Characterization Study, 1978)

On this day the AQML and R-28 obtained simultaneous upwind-downwind data across the Houston ship channel (Figure 16). The quality of the regional air was poor in terms of visibility, with the National Weather Service in Houston's Intercontinental Airport reporting extensive smoke and haze throughout the day. The day's average bsp was 2.7×10^{-4} m^{-1} upwind of the ship channel and 2.9×10^{-4} m^{-1} downwind of the ship channel. Diurnal variations of bsp, aerosol volume (> 0.5 μm), and CN are shown in Figures 25 and 26 for upwind and downwind of the ship channel. In both cases, aerosol volume and bsp decrease through the day.

The values for TSP were significantly different at the upwind and downwind locations. Upwind TSP values were 64 $\mu g/m^3$ during the day and 41 $\mu g/m^3$ during the night. Downwind of the ship channel, the TSP values were 183 $\mu g/m^3$ during the day, decreasing to 70 $\mu g/m^3$ at night. In both cases, the accumulation mode contributed the major portion of the total aerosol volume (Figure 27). The measured size distributions are incomplete these days at both sampling locations due to EAA failures. The variation in the size distribution during the day downwind of the ship channel, shows that the observed decrease in total aerosol volume is primarily due to a decrease in accumulation mode volume (Figure 28). This decrease also corresponds to the observed decrease in bsp.

The diurnal variation of gaseous pollutants (Figures 29 and 30) reveals specific changes in air quality downwind of the ship channel. Little diurnal variation between upwind and downwind sites is noted for O_3, except during the peak morning traffic period. The upwind site exhibits little, if any, O_3 depletion, while downwind of the ship channel, O_3 depletion is almost complete. O_3 maxima at both sites were recorded at 3 p.m. with 163 $\mu g/m^3$ and 144 $\mu g/m^3$ for the upwind and downwind sites respectively. Nitrogen oxide values were significantly greater downwind of the ship channel. The dominant species was NO_2, showing a maximum concentration of 91 $\mu g/m^3$. The most significant observation, however, was the presence of SO_2 downwind of the ship channel. No detectable concentrations of SO_2 were observed at the upwind site. The SO_2 concentration profile appears cyclic in nature; however, the frequency is not well defined.

October 2, 1978

The surface pressure gradient over the Houston area was quite weak on the 2nd. At the Radian monitoring trailer, which was located at Site 23 (Stude Park), wind speeds were very light during the early morning hours, and higher but still fairly light during the late morning and afternoon. Wind directions veered from southwesterly during the very early morning hours through northerly around sunrise (indicating the possibility of a land breeze), and finally to a generally southeasterly direction

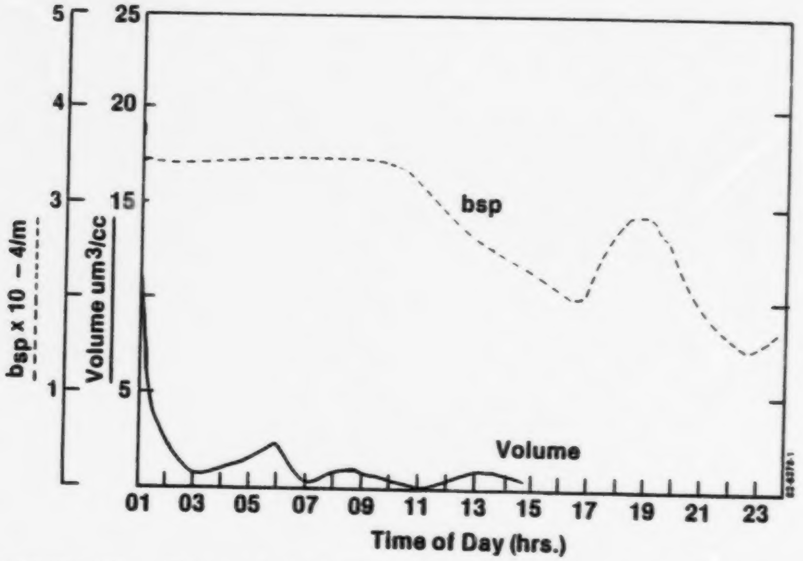


Figure 25. Diurnal Variation of Aerosol Measurements, Site 13, September 27, 1978 (Houston Aerosol Characterization Study, 1978).

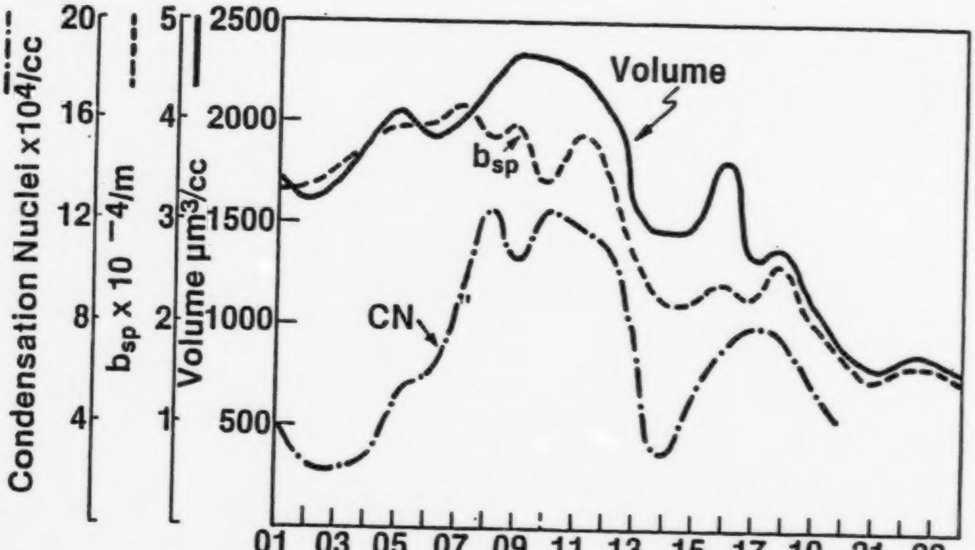


Figure 26. Diurnal Variation of Aerosol Measurements, Site 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978).

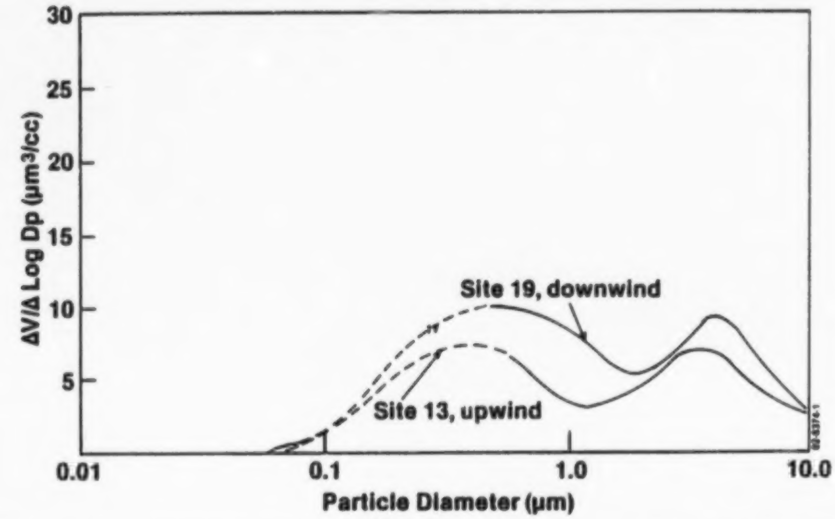


Figure 27. Average Daily Aerosol Volume Distributions, Sites 13 and 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978)

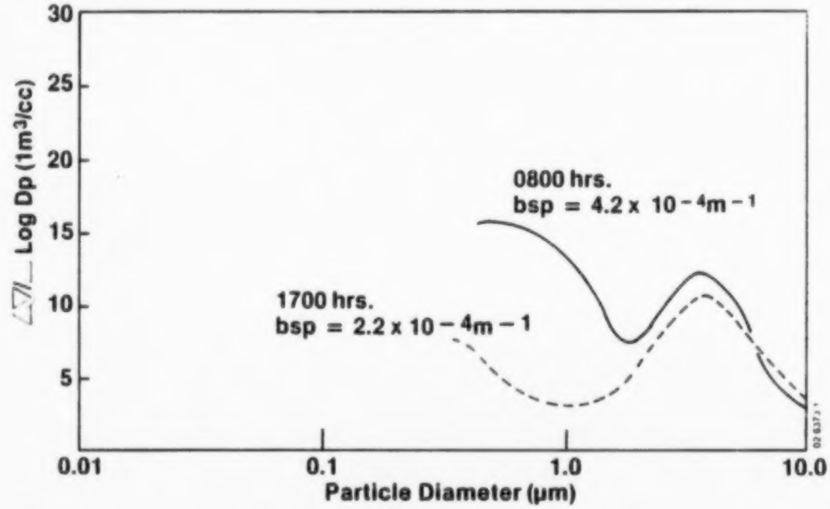


Figure 28. Aerosol Volume Distribution, Site 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978).

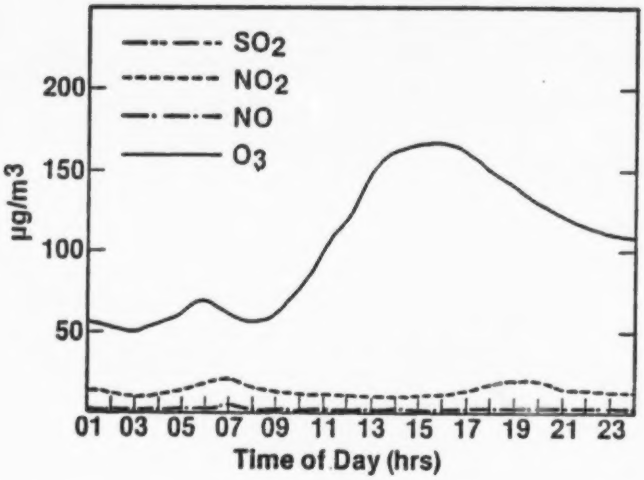


Figure 29. Diurnal Variation of Gaseous Constituents, Site 13, September 27, 1978 (Houston Aerosol Characterization Study, 1978)

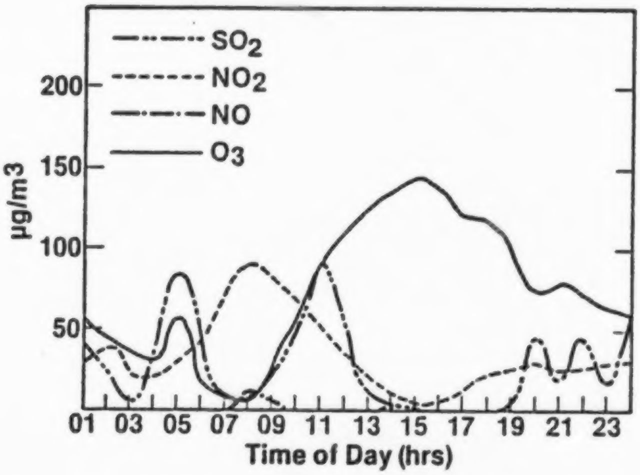


Figure 30. Diurnal Variation of Gaseous Constituents, Site 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978)

by late morning, bringing in maritime air. The wind direction remained generally southeasterly at least until 1700 CDT, the last hour for which wind direction data are available from the Radian trailer.

Upper level wind data from the pibal runs conducted at Radian's Houston office (Site 24) and at Pearland (Site 17) show that, from a few hundred feet above the surface up to about 9,000 feet, wind directions generally ranged from southerly through east-southeasterly over the Houston area. At least for the period from sunrise to mid or late morning, the data indicate that wind directions tended to rotate from south-southeasterly or southerly from a few hundred feet above the surface to southeasterly or east-southeasterly above 5,000 feet. Afternoon data suggest that winds were primarily south-southeasterly or southeasterly from above the surface to about 5,000 feet. Insufficient data are available to characterize the atmosphere above 5,000 feet during the afternoon.

Wind speed data from the two pibal sites show that wind speeds were generally moderate above 1,000 feet even during the period around sunrise, when surface winds were nearly calm. Therefore, downward transfer of momentum to the surface during atmospheric mixing after sunrise probably accounts for both the increase in surface wind speeds and the change of surface wind directions to southeasterly by late morning. At this time dispersion conditions began to improve significantly over the poor dispersion conditions of the previous four days.

It should be noted that a sea breeze effect may have enhanced the flow over the Houston area during the afternoon, but it is not easy to detect. Sea breeze effects are more evident on days during which wind speeds are very light up until the time of arrival of the sea breeze and wind directions rotate toward the southeast during the afternoon, not during the morning.

On this day, the AQML was located at Site 2 in the vicinity of the ship channel (Figure 17). R-28 was located at Site 23 near the urban core. Because winds were light and variable, data from this day must be interpreted with caution.

Values of bsp were similar at both locations, averaging 2.2×10^{-4} m^{-1} during the day. Maximum values observed were 3.3×10^{-4} m^{-1} at both locations and in each case occurred during early morning. At both locations, particle number maxima occurred during the peak morning traffic period (Figures 31 and 32).

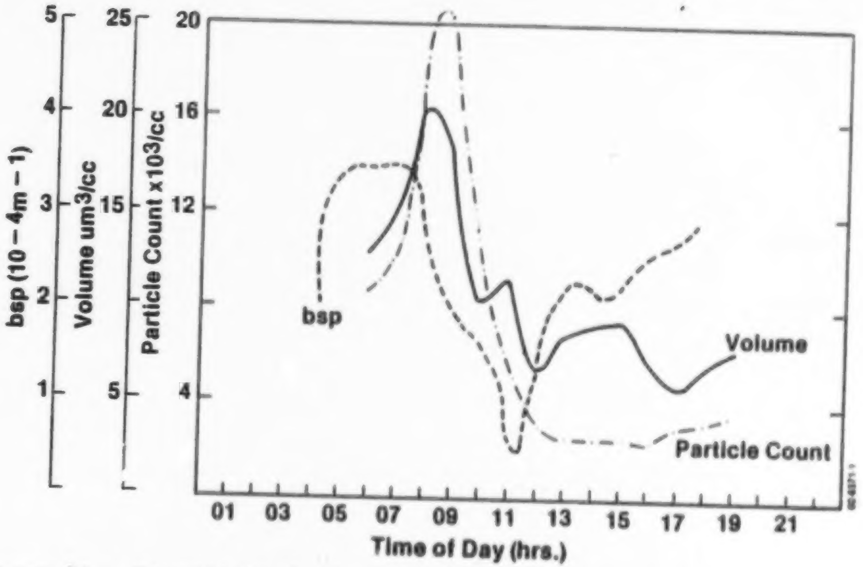


Figure 31. Diurnal Variation of Aerosol Measurements, Site 2, October 2, 1978 (Houston Aerosol Characterization Study, 1978).

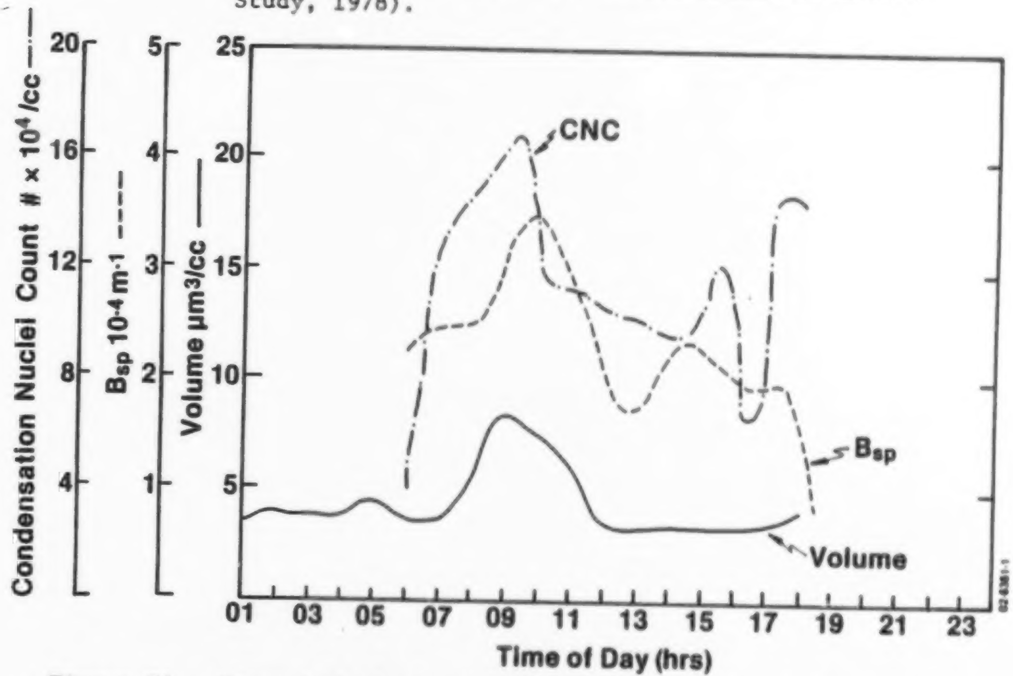


Figure 32. Diurnal Variation of Aerosol Measurements, Site 23, October 2, 1978 (Houston Aerosol Characterization Study, 1978).

The TSP values measured on this day were quite high; 244 μg/m³ in the area of the ship channel and 132 μg/m³ in the urban core. The particle size distributions (Figures 33 and 34) show that the accumulation mode was again dominant. The coarse particle mode VMD is 4.2 μm diameter and the GSD 1.9 in the ship channel area. The VMD of the accumulation mode is 0.58 μm, with a GSD of 1.5. There is also evidence of a nuclei mode, with a VMD of 0.024 μm diameter. The size distribution in the urban area is incomplete due to the EAA failure. The data available show a coarse particle mode VMD of 3.6 μm diameter and a GSD of 1.7. The accumulation mode appears to be shifted towards smaller particle sizes relative to the ship channel area's size distribution, with a correspondingly larger GSD.

The diurnal profiles for the gaseous pollutants (Figures 35 and 36) show maximum concentrations observed during the month long study. O_3 values reached 220 μg/m³ in both locations. NO maxima, coinciding with O_3 depletion during the peak morning traffic period, reached 646 μg/m³ adjacent to the ship channel and 768 μg/m³ in the urban core. Corresponding NO_2 maxima were 119 μg/m³ and 183 μg/m³, respectively. As previously observed, SO_2 was only detected in the ship channel area. Once again, the concentration profile appeared cyclic, with a maximum value of 63 μg/m³.

October 4, 1978

As a high pressure center moved eastward from North Central Texas, wind directions over the Houston area varied from northeasterly during the night and morning hours to southeasterly during the afternoon. At the Radian monitoring trailer, which was located at Site 17 (Pearland), wind direction data are available only for the last nine hours of the day. The data show that winds had become southeasterly at that location at least by mid afternoon. Wind speeds at Site 17 were light throughout the day, although higher during daylight hours than nighttime hours. According to Table 17, peak dispersion conditions on the 4th were fair.

Uutil surface winds turned to the southeast over the area during the afternoon, the air flowing into the area was continental in nature. With southeasterly winds during the afternoon, maritime air began flowing into the area.

Upper level wind data from the Radian office and Pearland pibal sites suggest that, from a few hundred feet above the surface to about 5,000 feet, wind directions over the Houston area generally rotated in a clockwise fashion with height. The rotation of wind direction was generally from east-northeasterly above the surface to east-southeasterly or southeasterly at about 5,000 feet during the morning, and from southeasterly to southeasterly during the afternoon. On the average, wind speeds below 5,000 were moderate over the area.

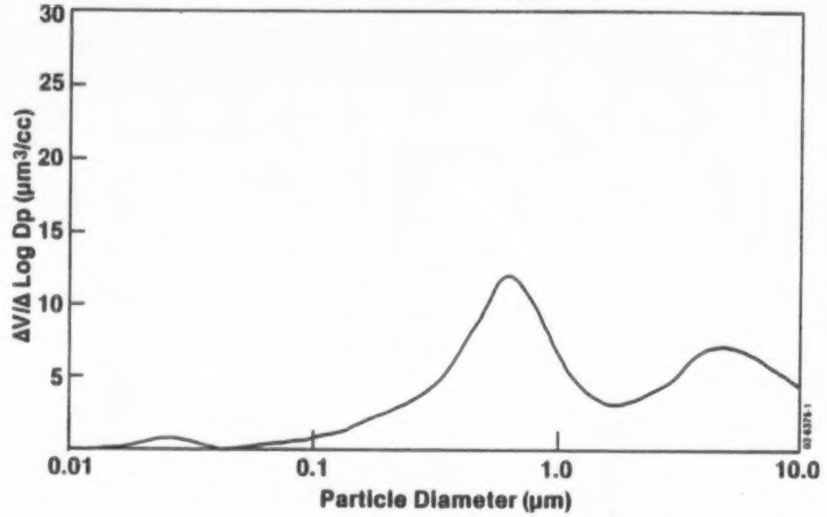


Figure 33. Daily Average Aerosol Volume Distribution, Site 2, October 2, 1978 (Houston Aerosol Characterization Study, 1978).

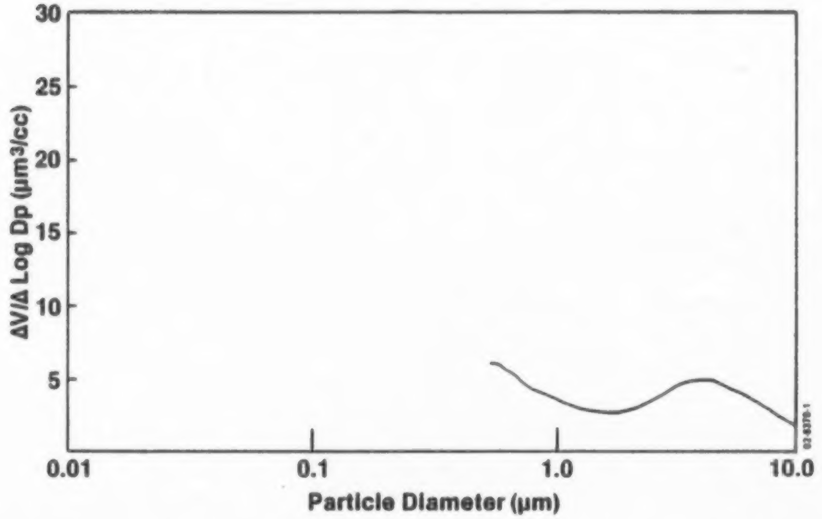


Figure 34. Aerosol Volume Distribution, Site 23, October 2, 1978 (Houston Aerosol Characterization Study, 1978).

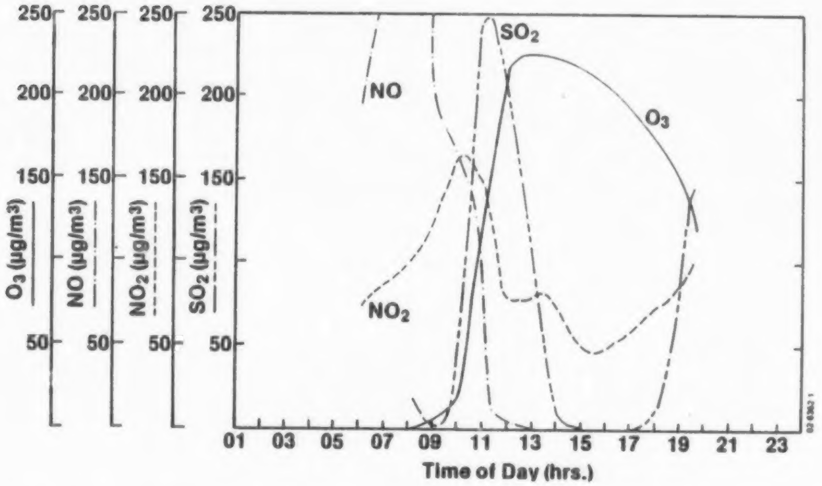


Figure 35. Diurnal Variation of Gaseous Constituents, Site 2, October 2, 1978 (Houston Aerosol Characterization Study, 1978).

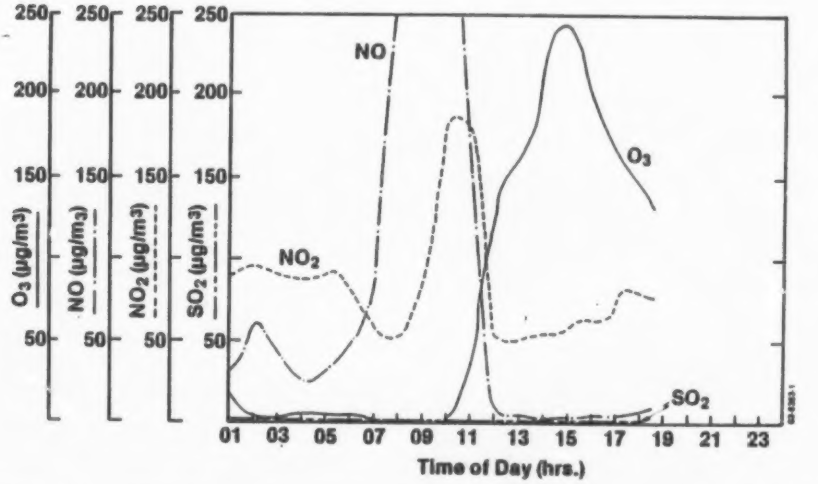


Figure 36. Diurnal Variation of Gaseous Constituents, Site 23, October 2, 1978 (Houston Aerosol Characterization Study, 1978).

The shift of wind directions below 5,000 feet to southeasterly or south-southeasterly during the afternoon can be attributed to the movement of high pressure eastward out of Texas. It should be mentioned, however, that a sea breeze effect may have slightly enhanced the shift toward these directions in the southern portion of the Houston area.

The AQML conducted mobile sampling during this day, covering an area in northwest Houston. The R-28 trailer was located at Site 17 (Figure 19). It is likely that Site 17 was influenced by ship channel emissions during the morning hours and incoming maritime air in the afternoon. The National Weather Service at Houston's Intercontinental Airport reported early morning fog and smoke and/or haze throughout the day.

South of Houston, at Site 17, bsp values averaged $1.8 \times 10^{-4}\ m^{-1}$, with the maximum values reported during the morning (Figure 37). CNC numbers and aerosol volume (> 0.5 µm) decreased steadily during the day.

The TSP values were similar on the north side of Houston and in the south, with 92 $\mu g/m^3$ and 97 $\mu g/m^3$ respectively. The volume size distribution for the south side is shown at two times of day (Figure 38). The previously noted decrease in aerosol volume appears to the result of a significant decrease in the volume associated with the coarse particle mode. Without information concerning the smaller particle sizes, a characterization of the accumulation mode is not possible. However, it appears that the VMD is shifted towards smaller particle size and that the GSD is large.

The diurnal plot of gaseous pollutants (Figure 39) shows a high O_3 maximum 229 $\mu g/m^3$. Of interest is a NO maxima (244 $\mu g/m^3$) at 4 a.m. and a build up of NO_2 (60 $\mu g/m^3$) prior to 7 a.m. A detectable amount of SO_2 was also observed around 8 a.m.

Sampling in Mobile Mode

The route followed by the AQML on this day is shown by Figure 40. The route was begun at 1504 and completed at 1647 hours CDT. The route started at site 20 on FM 1960, went south on Hwy. 6, east on U.S. 90, then north on Buffalo Speedway, east on Wroxton, and finally north on Montrose-Studewood as far as East 20th Street. The wind was from the south at approximately seven miles-per-hour during this period.

With this wind direction and speed, the mobile route first intersected the urban plume at a point where it had traveled for three hours downwind of the urban core. Later, the plume was intersected at a point about fifteen to thirty minutes downwind of the core. Most of the route followed roads and highways with relatively heavy traffic.

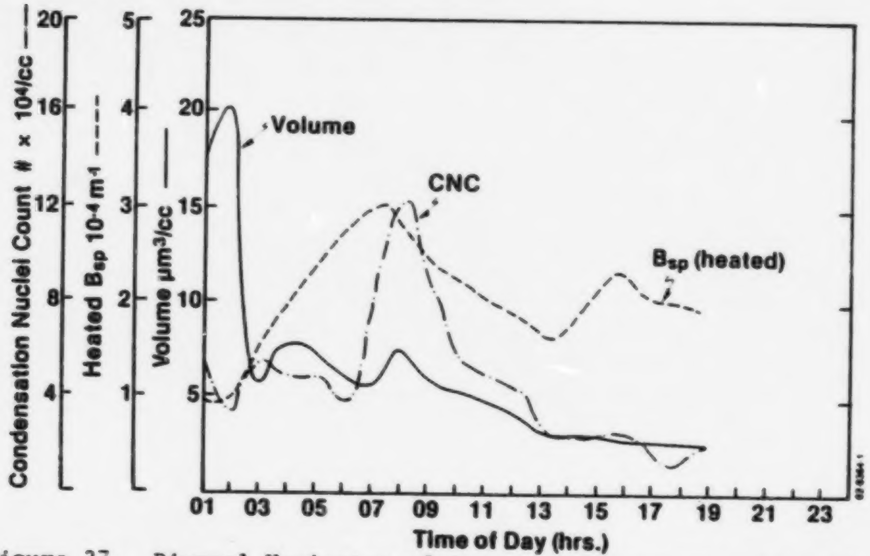


Figure 37. Diurnal Variation of Aerosol Measurements, Site 17, October 4, 1978 (Houston Aerosol Characterization Study, 1978).

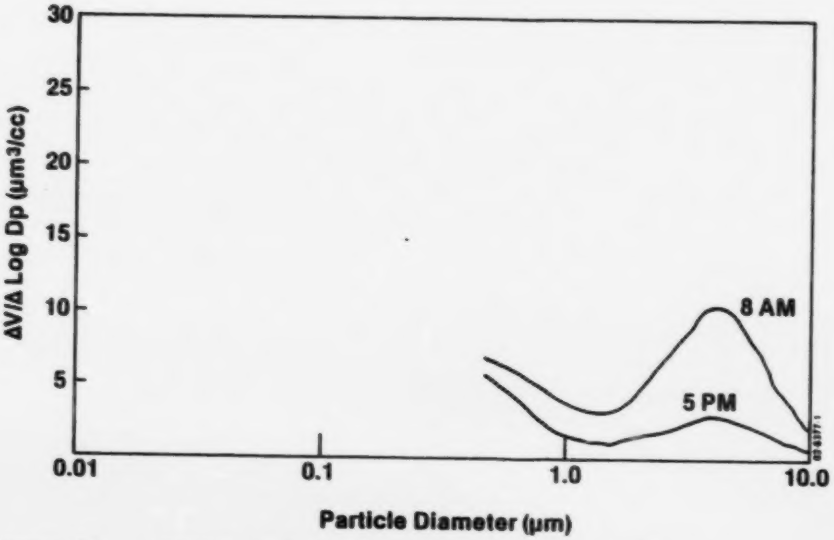


Figure 38. Aerosol Volume Distribution, Site 17, October 4, 1978 (Houston Aerosol Characterization Study, 1978)

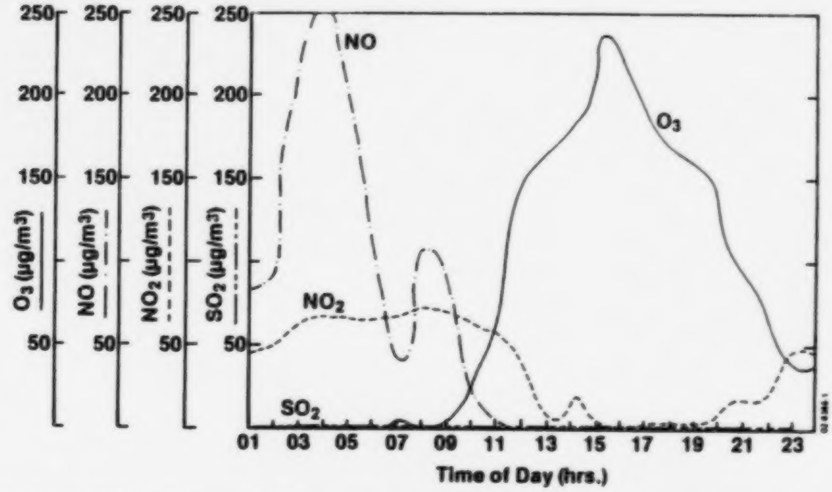


Figure 39. Diurnal Variation of Gaseous Constituents, Site 17, October 4, 1978 (Houston Aerosol Characterization Study, 1978).

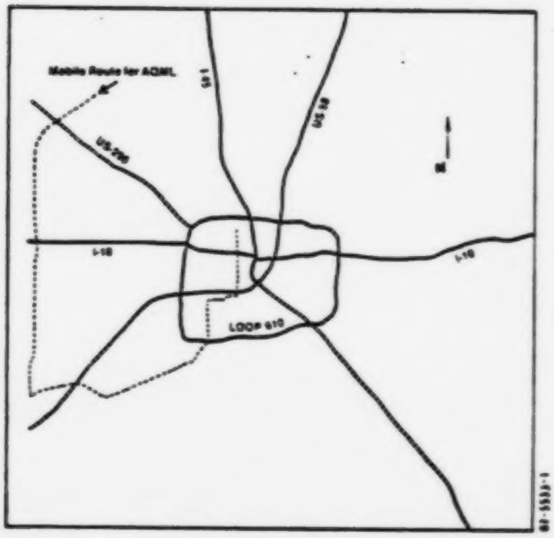

Mobile Route for AQML
I-45
US 59
US 290
N
I-10
I-10
LOOP 610

Figure 40. Mobile Route for AQML on October 4, 1978 (Houston Aerosol Characterization Study, 1978).

The monitoring results along the mobile route are depicted in Figures 41-44. Each figure depicts the route followed by the AQML, and gives the monitoring results for two parameters. Monitoring results are represented by the length of lines at frequent points along the route. The line for one parameter is at 135° relative to north, and for the other at 214° relative to north. The first figure (Figure 41) shows sulfur dioxide (135°) and carbon monoxide (215°) profiles for the route. The preponderance of carbon monoxide near the center of the city is easily seen. The spikes at other locations may be due to local traffic. Except for a few spikes, sulfur dioxide was not present at a significant level. Due to the lack of SO_2 adjacent to the spikes this probably indicates the sources were local.

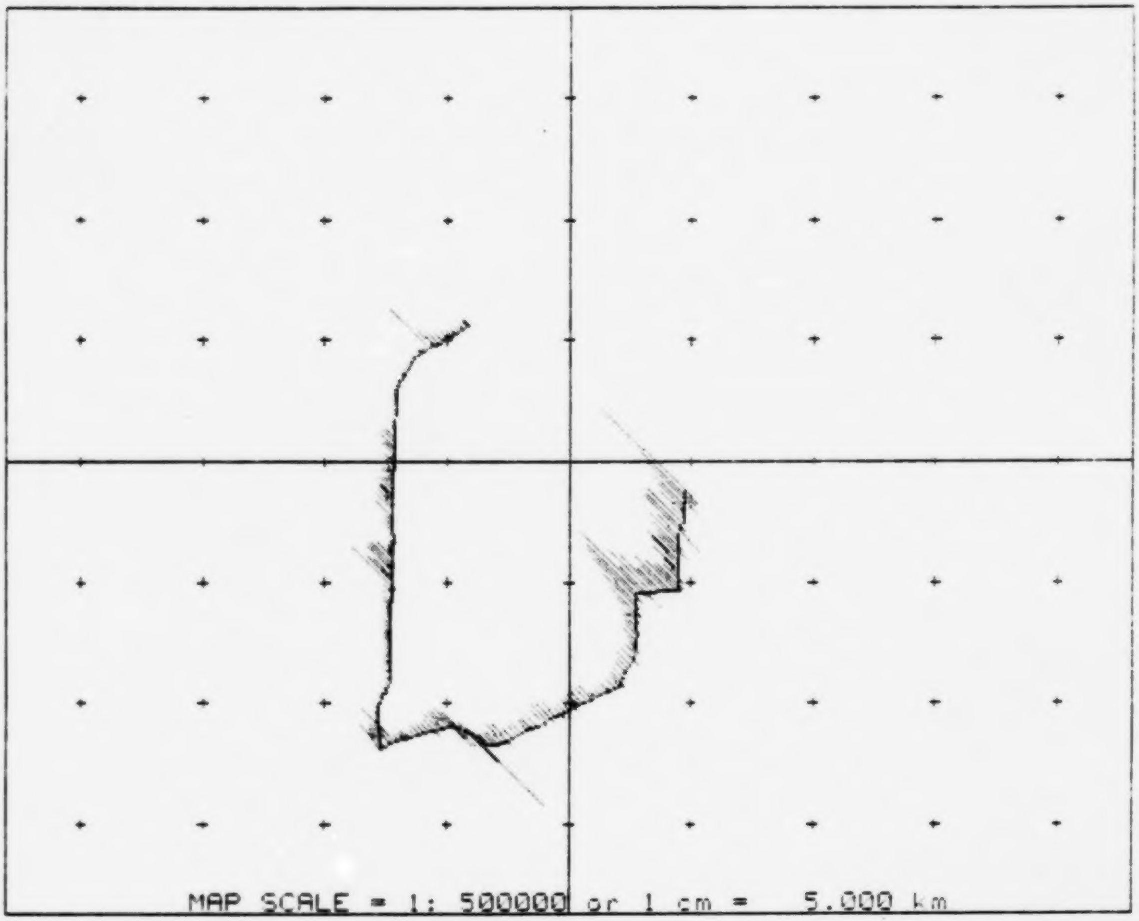
Figure 42 shows the profiles for the nephelometer (135°) and solar radiation (215°). Variations in the solar radiation along the route are probably attributable to cloud cover, tall buildings, or trees. Visibility was quite uniform over the area.

The profiles for the two ozone instruments are given in Figure 43. The chemiluminescent response is at 215°, and the UV is at 135°. Generally speaking, there was good agreement between the two instruments. It can be seen that ozone levels were higher at the downwind location than near the center city. Otherwise the ozone levels appear to be quite uniform over a wide area.

Nitric oxide and nitrogen dioxide levels are given in Figure 44. Both species exhibit wide variations, possibly due to local traffic influences. Generally both species are higher near the center city than at the downwind location. Although dilution is undoubtedly a contributor to this, the low NO_2 levels are somewhat surprising for the downwind site. Possibly local sources are preventing the true area NO_x profiles from manifesting themselves.

October 8, 1978

On this day, the Houston area was under the influence of a ridge of high pressure which extended southwestward into Texas from the Ohio Valley. At the Radian monitoring trailer, which was located at Site 21 (Alief), the wind direction varied in a clockwise fashion from northerly very early in the morning to northeasterly by sunrise, easterly by mid-morning, and east-southeasterly by early afternoon. Winds continued to be east-southeasterly during the remainder of the day. Surface wind speeds were rather light during the early morning hours, but were moderate in strength from mid-morning until early evening, when wind speeds became light.


MAP SCALE = 1: 500000 or 1 cm = 5.000 km

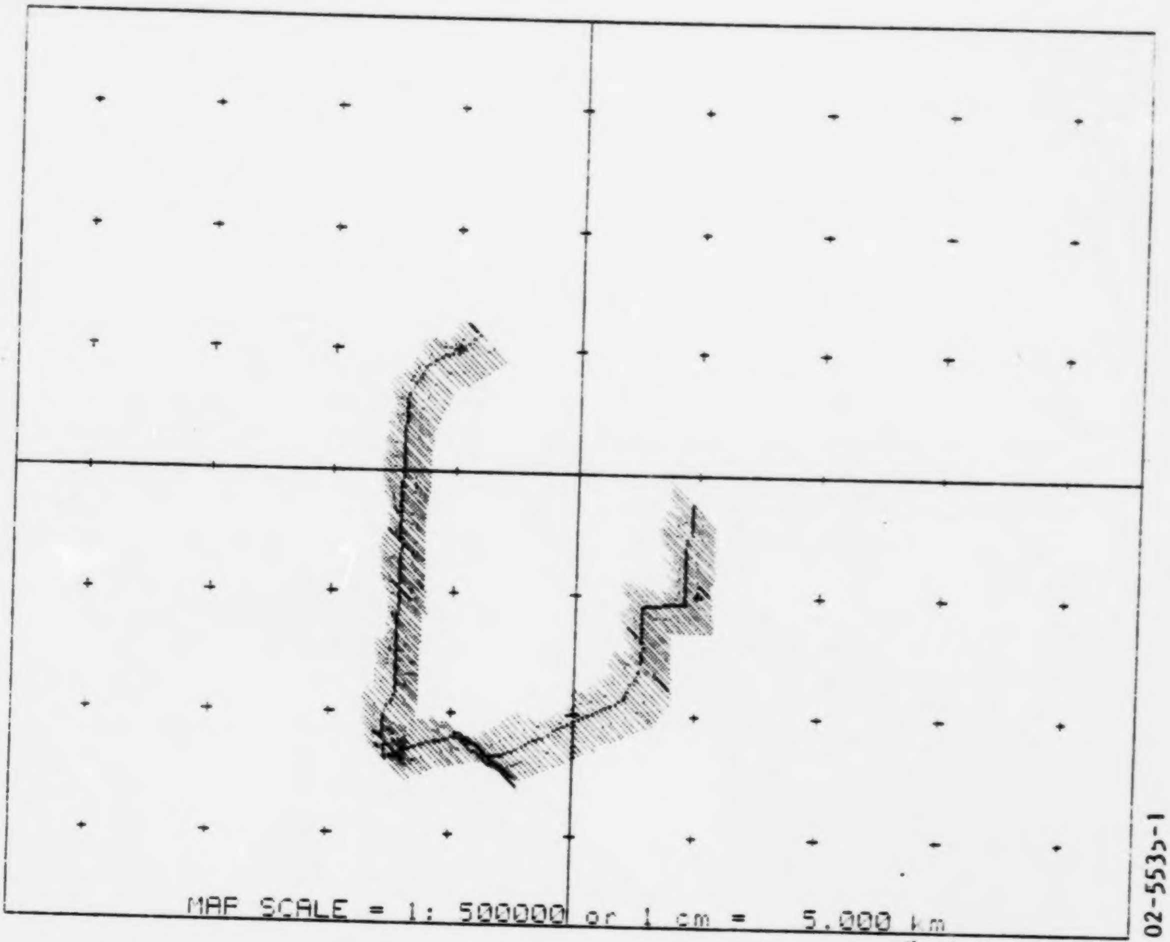
02-5534-1

DATE: OCTOBER 4, 1978
SO_2 is at 135 Dg; CO is at 215 Dg from North*
SO_2: 1 Centimeter = 50ppb; CO: 1 Centimeter = 25ppm

TIMES: 1504 - 1647 CDT

*NOTE: Quality Assurance audits revealed significant error in the CO Measurements.

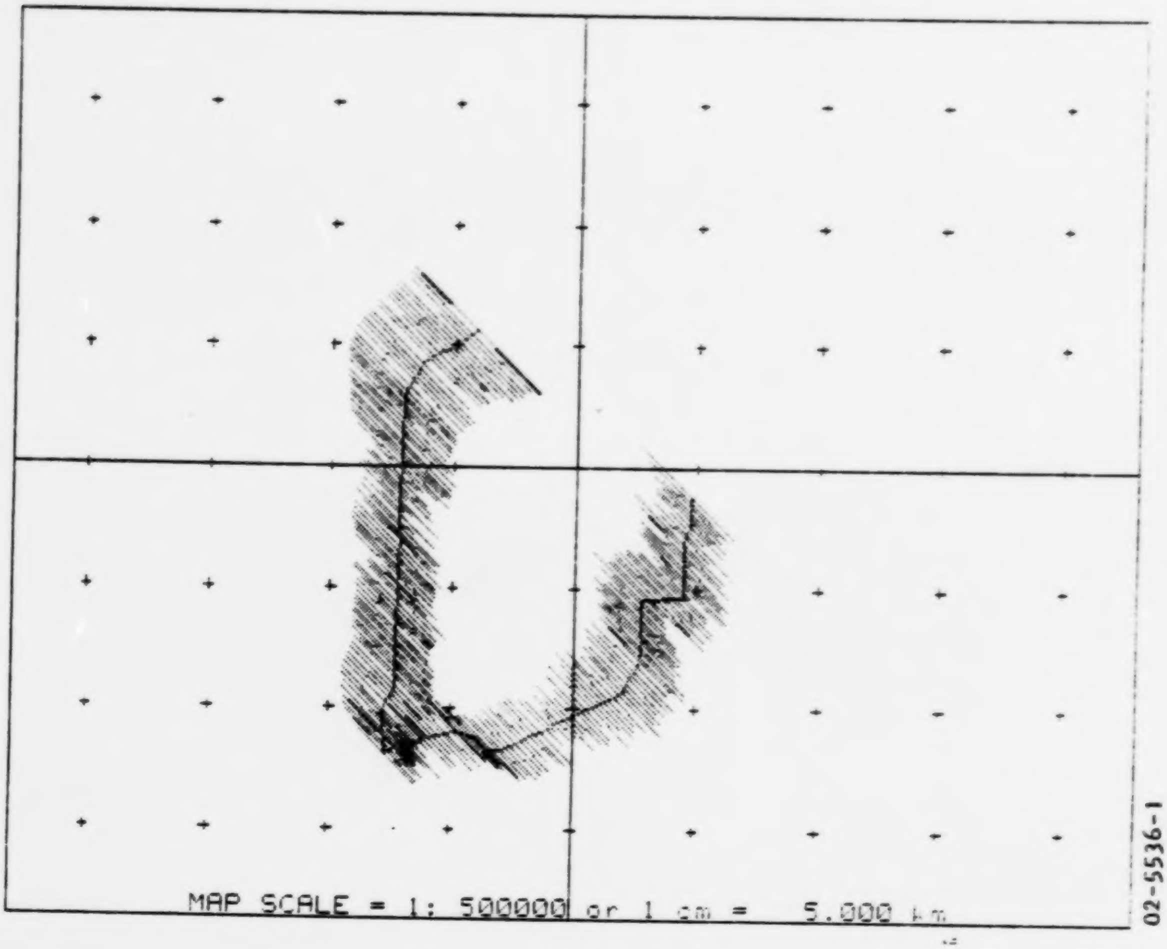
Figure 41. Sulfur Dioxide and Carbon Monoxide Profiles (Houston Aerosol Characterization Study, 1978).


MAP SCALE = 1: 500000 or 1 cm = 5.000 km
02-5535-1

DATE: OCTOBER 4, 1978
bS-h is at 135 Dg; Rad2 is at 215 Dg from North
bS-h: 1 Centimeter = 5 x $10^4 m^1$; Rad: Centimeter = 25 ly/mn

TIMES: 1504 - 1647 CDT

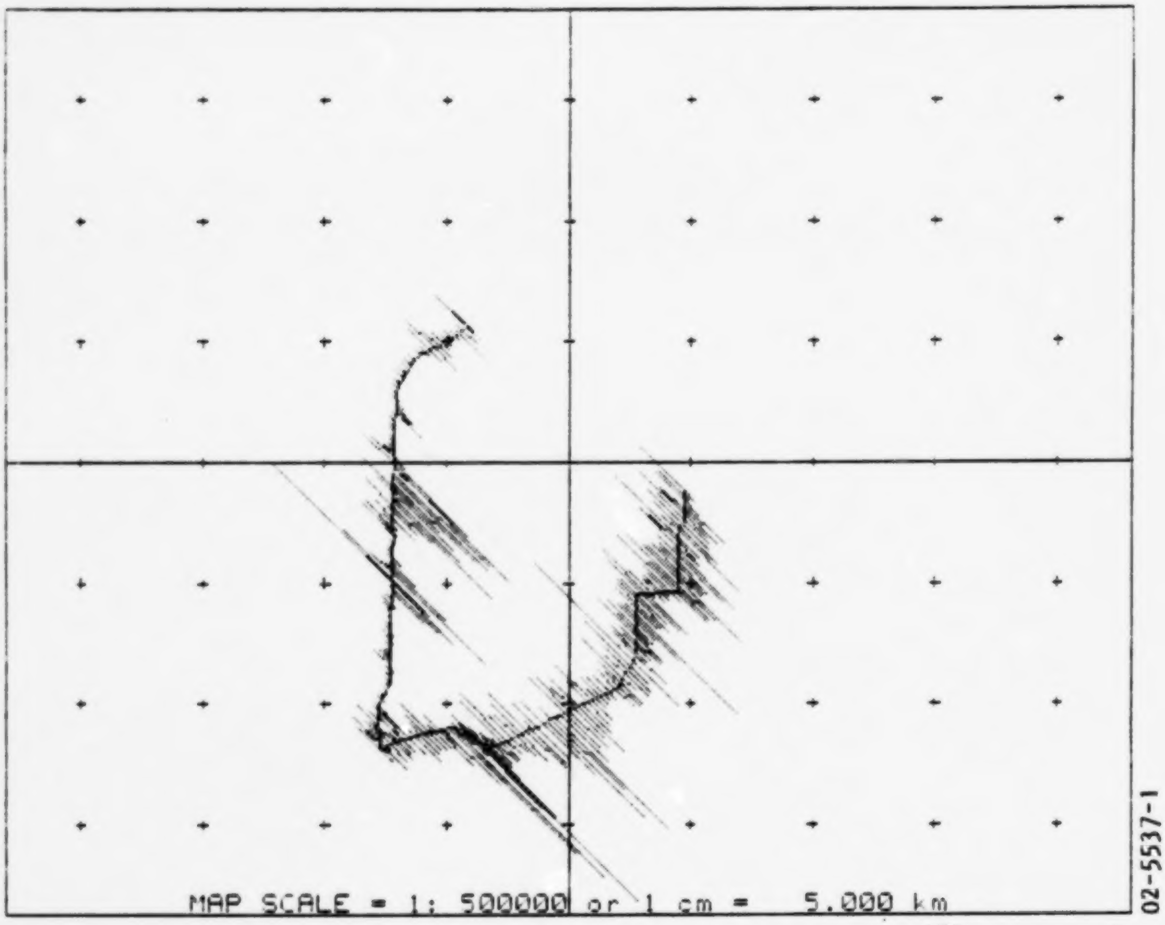
Figure 42. Nephelometer and Solar Radiation Profiles (Houston Aerosol Characterization Study, 1978).


MAP SCALE = 1: 500000 or 1 cm = 5.000 km
02-5536-1

DATE: OCTOBER 4, 1978
03-D is at 135 Dg; 03-B is at 215 Dg from North
1 Centimeter = 100ppb

TIMES: 1504 - 1647 CDT

Figure 43. Ozone Profiles for AQML. (Houston Aerosol Characterization Study, 1978).


MAP SCALE = 1: 500000 or 1 cm = 5.000 km
02-5537-1

DATE: OCTOBER 4, 1978
No is at 135 Dg; NO_2 is at 215 Dg from North
1 Centimeter = 100ppb

TIMES: 1504 - 1647 CDT

Figure 44. Nitric Oxide Profiles for AQML. (Houston Aerosol Characterization Study, 1978).

Although surface winds became east-southeasterly during the early afternoon, allowing the possibility that the air crossed over water, the orientation of the high pressure ridge extending into Texas was such that the trajectory of the air over water was probably very short. The air was primarily continental in nature, as evidenced by the low dew points recorded at the Radian trailer.

Upper level wind data from the Radian office pibal site (Brookhollow, Site 24) shows that, up until early afternoon, winds at that location were easterly from a few hundred feet above the surface to about 5,000 feet. Between 5,000 and 10,000 feet, winds tended to rotate toward a northerly direction with some northwesterly winds near 10,000 feet. At the Pearland pibal site, wind directions up until early afternoon were similar, except that some east-northeasterly winds were evident a few hundred feet above the surface. At both sites, wind speeds during this period were moderate to strong even around sunrise, at least up to 7,000 or 8,000 feet. There is an insufficient amount of data to fully characterize upper levels from mid-to-late afternoon; however, existing data for both sites suggest that winds up to 3,000 or 4,000 feet turned toward the east-southeast or southeast around mid-afternoon and remained moderate to strong. As indicated in Table 17, peak dispersion conditions were good on this day.

Because wind speeds were moderate to strong above the surface even during the period around sunrise, the increase in surface winds at the Radian trailer site at mid-morning was the result of the downward transfer of momentum from aloft during atmospheric mixing. The momentum transfer was also responsible for the shift in wind direction to easterly at mid-morning. The shift of wind directions toward the east-southeast during the afternoon at both the surface and aloft was probably caused primarily by a shift in the orientation of the synoptic pressure gradient. A sea breeze effect was probably not responsible, since the shift toward the east-southeast was evident in the Radian site pibal data by early afternoon and a sea breeze effect would not be expected to penetrate so far inland until later in the day.

Site 21, where the R-28 trailer was located, is west southwest of the urban core and ship channel (Figure 20). As a result of the shifting winds, the site was probably influenced by both the urban plume and the ship channel plume. The AQML was located upwind of both the urban core and the ship channel in the vicinity of Baytown (Site 22). It is expected that, due to the variable wind speed and direction, local sources probably influenced the air quality. Therefore, this site should not be interpreted as representing incoming continental air.

Visibility at both locations, east and west of the city, was good, with bsp values averaging $0.7 \times 10^{-4}\ m^{-1}$ during the day. Maximum values of bsp at both locations occurred during the morning (Figure 45 and 46). These maxima also corresponded to increases in particle number and aerosol volume.

Coinciding with these events were the detection of relatively large amounts of SO_2 at both sites (Figures 47 and 48). High concentrations of NO and NO_2 were recorded west of the city. The maximum NO value (342 $\mu g/m^3$) was again observed to occur early in the morning (4 AM), with a significant NO_2 buildup (75 $\mu g/m^3$) also present prior to 7 AM. Ozone maxima were 122 $\mu g/m^3$ and 147 $\mu g/m^3$ at the locations east and west of the city, respectively.

The volume particle size distribution was rather consistent throughout the day west of the city (Figure 49). The coarse particle mode contributed 80 percent of the total mass. The coarse particle mode VMD was 3.9 μm diameter and the GSD was 1.7. The accumulation mode VMD was 0.45 μm diameter and the GSD 1.9. To the east of the city, a significant change was observed in the volume particle size distribution (Figure 50). The magnitude of the accumulation mode was observed to decrease during the day while the coarse particle mode increased slightly. The VMD of the accumulation mode remained at approximately 0.27 μm diameter. The coarse particle mode VMD increased slightly during the day from 4 μm to 4.6 μm diameter.

DISCUSSION OF RESULTS

Although an interpretive discussion is beyond the scope of this initial presentation of results, several trends and observations are evident. The discussion will be directed at

- aerosol related topics, including visibility,
- gaseous pollutant profiles, and
- comparison with other cities.

Aerosols

Each of the major source areas appears to be characterized by the associated particulate burden and aerosol size distribution. Table 18 lists these sources and the portion of total aerosol volume contributed by the accumulation mode and the coarse particle mode. The accumulation mode can, in most cases, be thought of as the respirable fraction of the aerosol (Figures 51 and 52). Because of the adverse health effects associated with particles in this size range, it is useful to provide an indication of not only total suspended particulate burden, but also the particulate burden contributed by this size fraction. Table 19

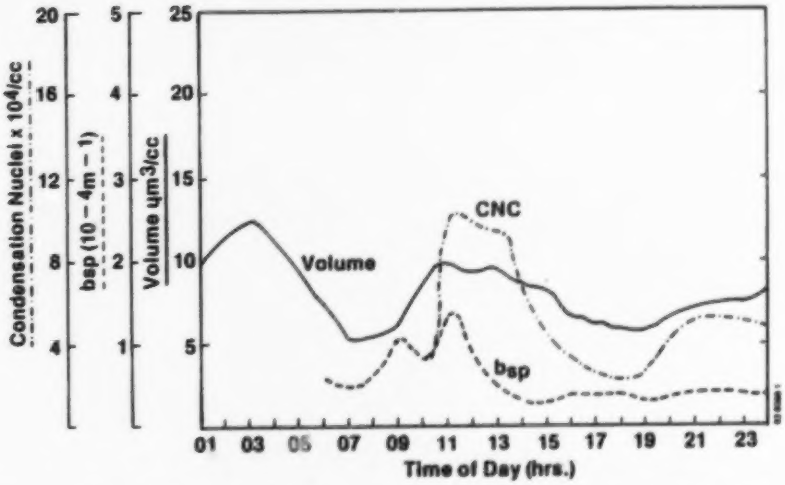


Figure 45. Diurnal Variation of Aerosol Measurements, Site 21, October 8, 1978 (Houston Aerosol Characterization Study, 1978).

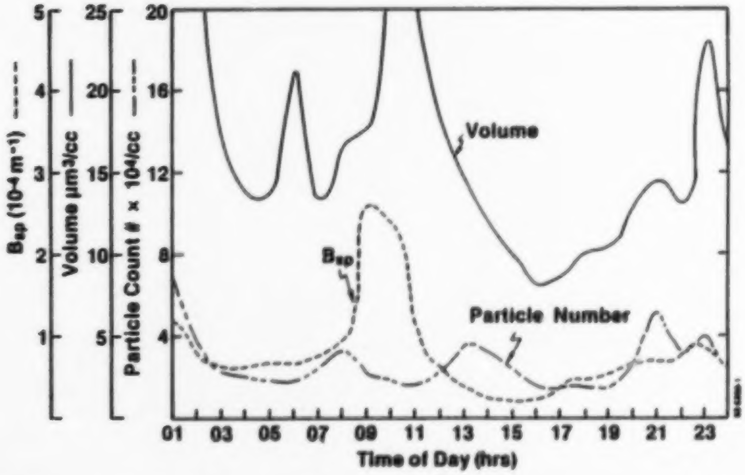


Figure 46. Diurnal Variation of Aerosol Measurements, Site 22, October 8, 1978 (Houston Aerosol Characterization Study, 1978).

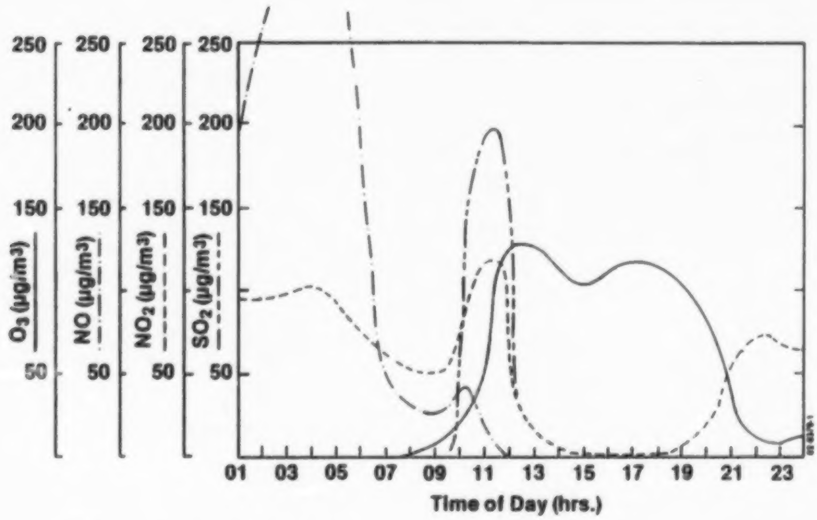


Figure 47. Diurnal Variation of Gaseous Constituents, Site 21, October 8, 1978 (Houston Aerosol Characterization Study, 1978).

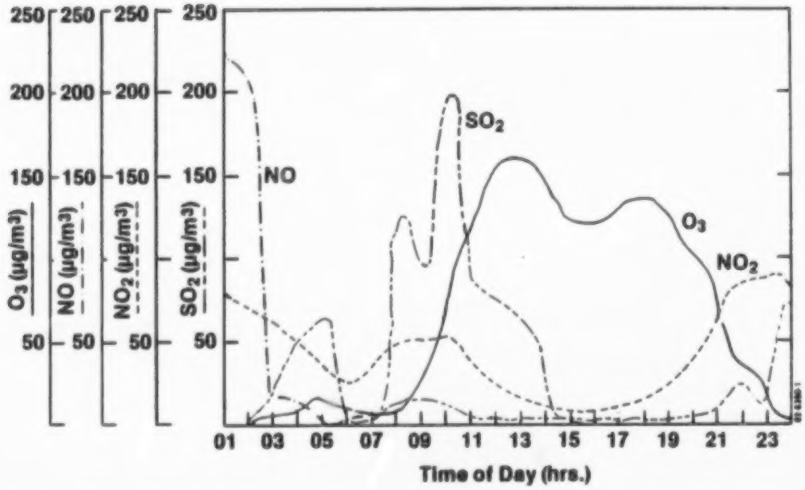


Figure 48. Diurnal Variation of Gaseous Constituents, Site 22, October 8, 1978 (Houston Aerosol Characterization Study, 1978).

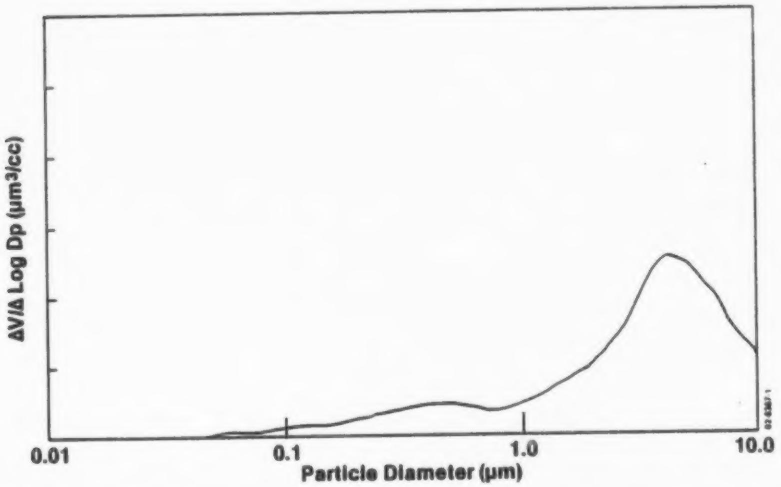


Figure 49. Daily Average Aerosol Volume Distribution, Site 21 October 8, 1978 (Houston Aerosol Characterization Study, 1978).

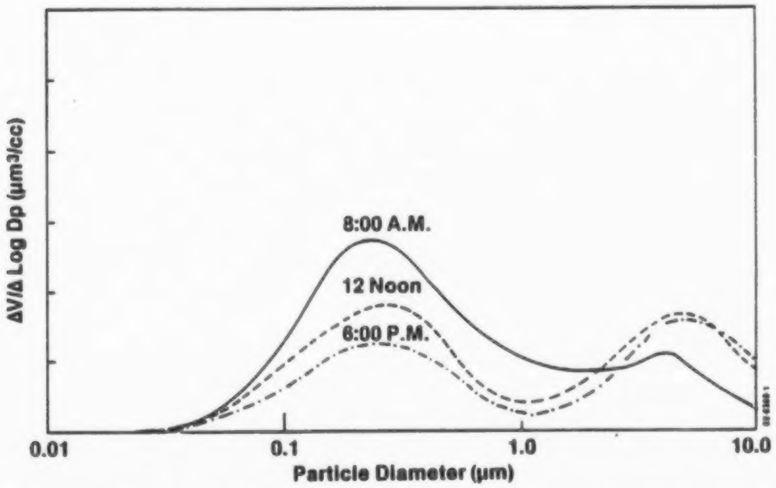


Figure 50. Aerosol Volume Distributions, Site 22, October 8, 1978 (Houston Aerosol Characterization Study, 1978).

TABLE 18. SUMMARY OF AEROSOL VOLUME DISTRIBUTIONS

	Fraction of Total Aerosol Volume	
Source Area	Accumulation Mode	Coarse Mode
Incoming Maritime Air*	0.25	0.75
Incoming Continental Air	0.70-0.80	0.20-0.30
Urban Core	0.90	0.10
Ship Channel	0.25-0.70	0.30-0.75

*May be Influenced by Anthropogenic Sources

TABLE 19. SUMMARY OF PARTICULATE BURDENS

	Nominal Particulate Burden ($\mu g/m^3$)	
Source Area	Total	Respirable
Incoming Maritime Air	80	20
Pristine Maritime Air	25	No Measurements Obtained
Incoming Continental Air	60	40-50
Urban Core	100	90
Ship Channel	120	30-80

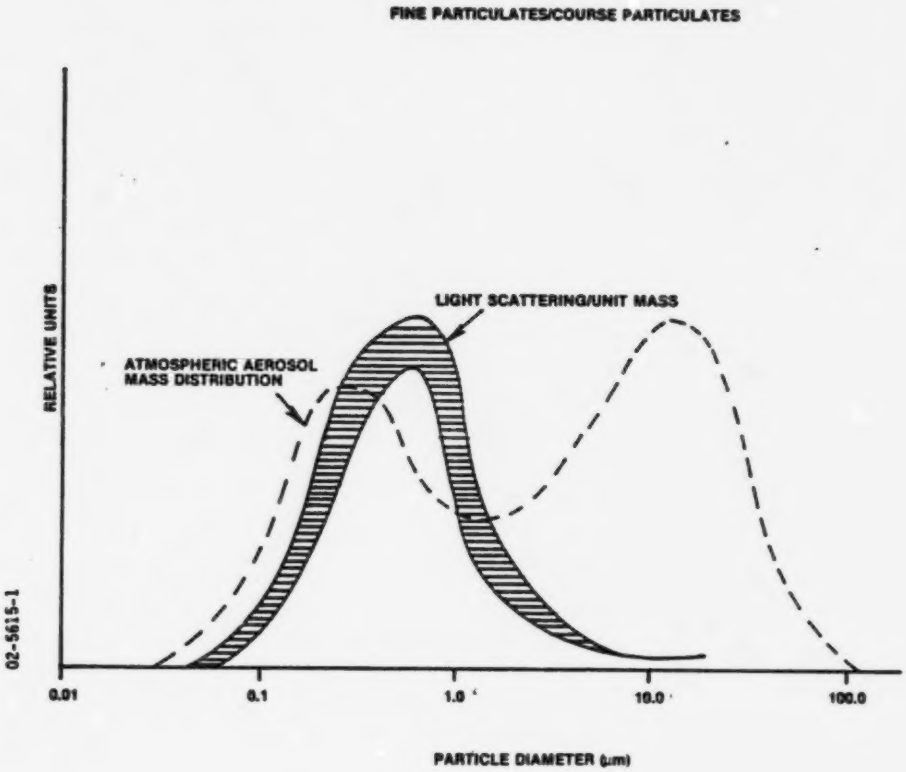


Figure 51. Typical Ambient Aerosol Characteristics (Redrawn from Charlson, Waggoner & Thielke, "Visibility Protection for Class I Areas: The Technical Basis" PB-288 842, National Technical Information Service, Washington, D.C. 1978).

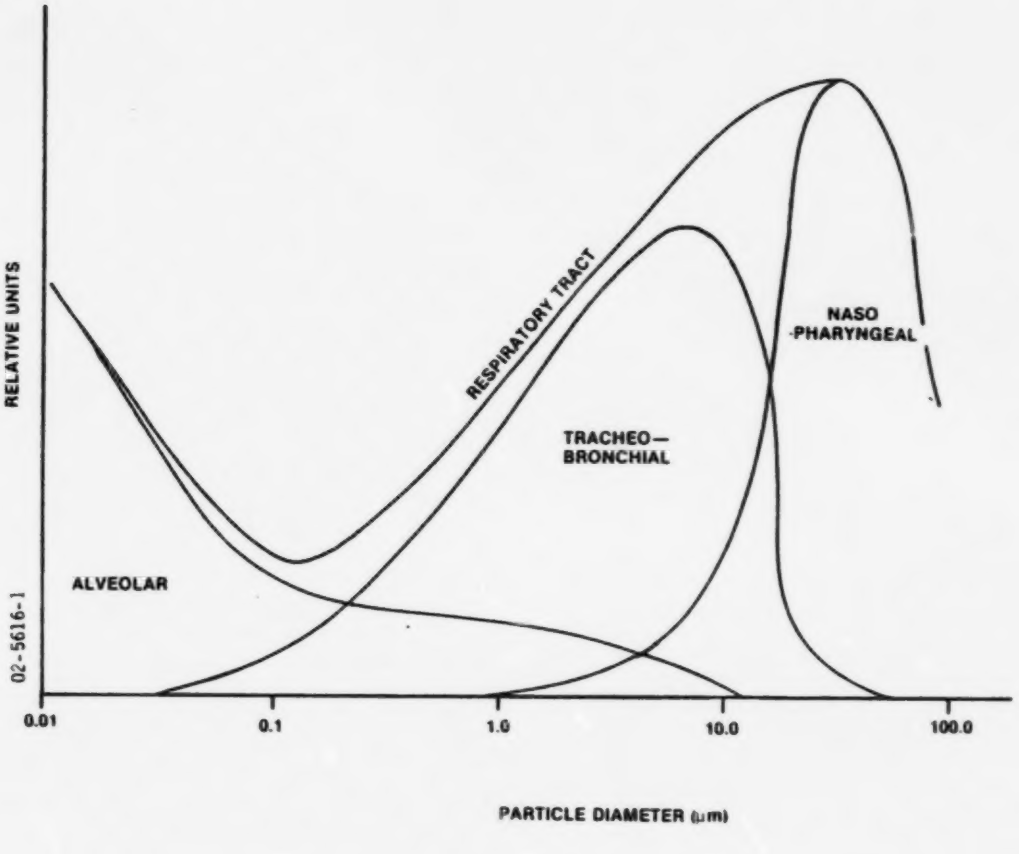


Figure 52. Deposition rates of aerosols in human respiratory tract (Ronald E. Engel, "Potential Hazards as a Result of Inhalation of Radioiodine, a Literature Survey," U.S.A.E.C., June, 1966).

presents these data for each of the major source areas studied. The respirable particulate burden was calculated based upon the percentage of average aerosol volume less than 2.5 μm in diameter and the nominal TSP values shown.

Of interest is the variation observed in particle size distribution downwind of the Houston ship channel during periods of maritime and continental flow. The ultimate distribution appears to reflect the background gradient flow. A dominant accumulation mode is observed during periods of incoming continental air, while a dominant coarse particle mode exists during incoming maritime air. This would indicate that the particulate contribution by the ship channel industry is approximately equal for the coarse and fine particle fractions.

The size distributions downwind of the urban core and the ship channel both exhibit significantly larger GSD of the accumulation mode. The GSD is a measure of the spread of the distribution about the mean. Small values of the GSD, such as those observed for incoming continental air (1.7) and incoming maritime air (1.8), usually indicate an aged aerosol. Larger values of GSD, such as those observed for the ship channel (2.5) and urban (2.2) plumes, can be interpreted as being active aerosol systems undergoing transformation through processes of agglomeration and condensation.*

The particle size distributions observed throughout the Houston study were always at least bimodal. Many times, trimodal distributions were observed, i.e., a nuclei mode was also detected. These observations were almost always limited to peak morning traffic periods. However, they were observed at almost every monitoring site. The presence of the nuclei mode is attributed to the local effects of automobile exhausts. The fact that this effect was observed over much of Houston is indicative of the high automobile density in the area.

The accumulation mode was referred to above as being responsible for the major fracion of repirable particles. It is also responsible for the major portion of light scattering attributed to particles (vs. molecular scattering) (Figure 51). As such, the mass of the accumulation mode (especially between 0.1 and 1.0 μm diameter) has in the past been highly correlated with visibility (bsp).[16]

The particle scattering coefficient (bsp) was observed, for the most part, to decrease during the day, with maximum values recorded during the early morning hours. Total aerosol volume also tended to decrease during the day, coinciding with a decrease in bsp. In many of the cases, the major cause of the decrease in aerosol volume was due to a reduction of the accumulation mode. Figures 53 and 54 show several examples of the decrease observed for bsp during the day and the corresponding change in particle size distribution. It is apparent that the accumulation mode is responsible for particle scattering in Houston.

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*This implies that this aerosol is the result of secondary reactions of emissions from the urban area and ship channel areas.

The results of experiments using a heated nephelometer provided insight about the extent to which moisture affected visibility reduction. Ambient relative humidity (RH) in the Houston area was observed to vary between 60 percent and 100 percent. The early morning hours were routinely high RH, and the afternoon hours low RH. The heated nephelometer was operated side-by-side with a nephelometer sampling air at ambient temperatures. Figure 55 presents the data collected over a 24 hour period at a location downwind of the ship channel, during a period of maritime flow. The bsp measured by the heated nephelometer was less at all times than the bsp measured with the nephelometer kept at ambient temperatures. The measured difference between the two nephelometers was observed to be greatest during the morning and much less in the afternoon. A plot of this difference (bsp-bsp heated) versus the corresponding RH (Figure 56) results in a good correlation (R^2=0.75). An exponential fit would not significantly increase the correlation coefficient because the data are highly scattered. The results are similar for other days, but the data are not complete enough to differentiate the various source areas. It is evident, however, that at a RH greater than 60 percent, the measured bsp can be significantly increased by volatile water associated with the particulates. This fact may partially explain the observed early morning bsp maxima.

All during the Houston study, poor visibility appeared to be an areawide phenomenon. Differences in visibility upwind and downwind of the urban core or ship channel were not significant. No specific conditions were documented as routinely leading to periods of poor visibility.

Gaseous Pollutants

The diurnal variations of gaseous pollutants were, for the most part, typical of those associated with urban areas. During the period of continental air flow, ozone values were much greater (160 $\mu g/m^3$) than might be expected upwind of the urban-ship channel area. The source is not clear at this time; however, local effects were probably not significant. Long range transport can not be ruled out, although other researchers have attributed high ozone concentrations to stratospheric intrusion.[17]

Nitrogen oxides were observed to buildup overnight during those periods when a dominant gradient flow did not exist. During these periods, complete ozone depletion occurred in the mornings and evenings. Ozone often persisted through the night when a gradient flow did exist.

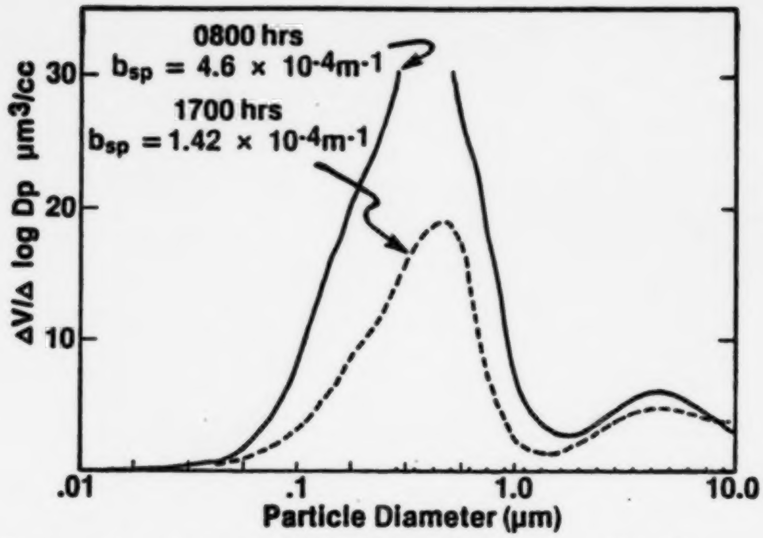

Figure 53. Aerosol Volume Distributions, Site 20, September 27, 1978 (Houston Aerosol Characterization Study, 1978).

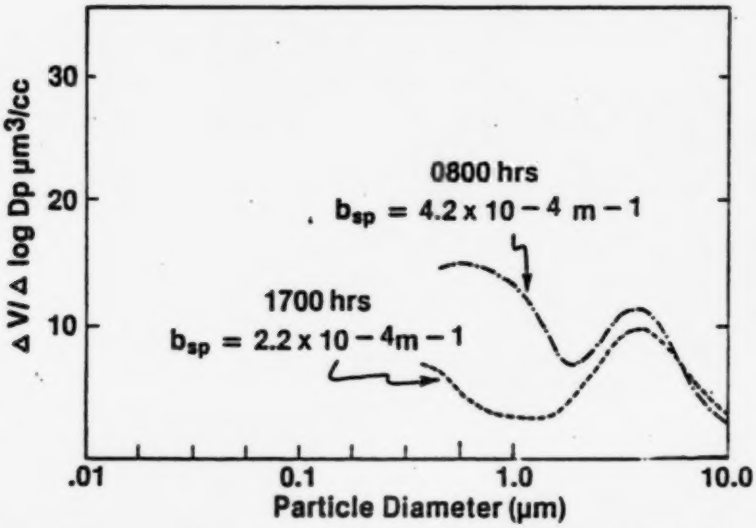

Figure 54. Aerosol Volume Distributions, Site 19, October 3, 1978 (Houston Aerosol Characterization Study, 1978).

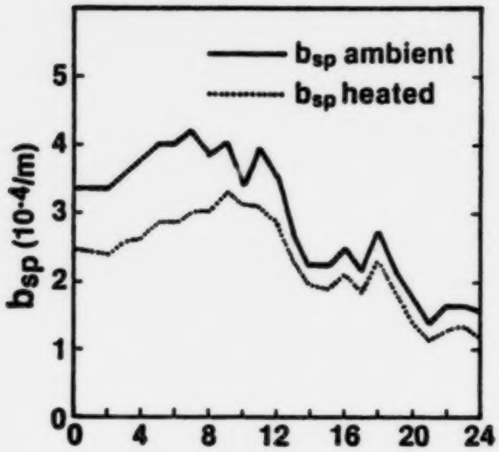

Figure 55. Diurnal Variation of Light Scattering Measurements, Site 19, September 27, 1978 (Houston Aerosol Characterization Study, 1978).

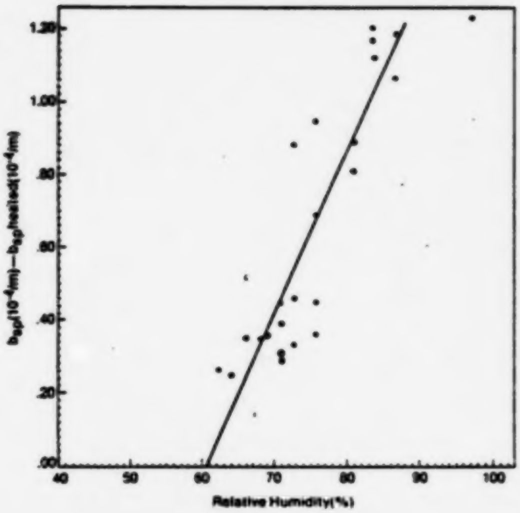

Figure 56. Scattergram of Light Scattering vs. Relative Humidity (Houston Aerosol Characterization Study, 1978).

Nitrogen dioxide was observed to build up to a maximum, following the morning NO peak, downwind of both the ship channel and urban area. However, although the levels of NO_2 persisted through the day downwind of the urban core, they decreased during midday downwind of the ship channel. This difference may be due to large concentrations of reactive hydrocarbons downwind of the ship channel. Photochemically-induced hydrocarbon radical reactions could be expected to serve as a sink for NO_2, resulting in the production of peroxyacetyl nitrate (PAN) and other compounds.

Sulfur dioxide was only observed downwind of the ship channel. The diurnal profile in all cases appeared to be intermittent (Figure 57) and, as such, may be correlated to a batch type process. Consistent SO_2 maxima were observed between 1000 and 1200 hours and between 2200 and 2400 hours.

Comparison With Other Studies

Previous researchers have detailed diurnal gaseous pollutant profiles, such as those shown in Figure 58, for Pasadena, California.[18,19] The profile shown in Figure 59 for Houston shows no significant difference with the profile for Los Angeles and other major urban centers.

The build-up of a photochemical smog and subsequent visibility reduction has been documented during previous studies (Figure 60).[20,21] The decrease in visibility has been attributed to the build-up of the accumulation mode, as documented during this study (Figure 53). The build-up occurred during midday, and was explained as the result of photochemical reactions. The Houston study, however, did not show this pattern. Maximum bsp and aerosol volumes routinely occurred during the early morning. The extent to which RH and/or an increase in mixing height contributed to this difference is not clear. Photochemical activity was evident as broad maxima of condensation nuclei.

Previous studies have documented a correlation between bsp and O_3 (Figure 61).[22,23] This was interpreted as supporting the role of photochemistry in visibility reduction. Such a correlation did not exist during this study, as shown in Figure 62. Attempts to correlate bsp with other indicators of photochemical reactions (NO_2, NO, SO_2 and CNC) produced no indications of a relationship.

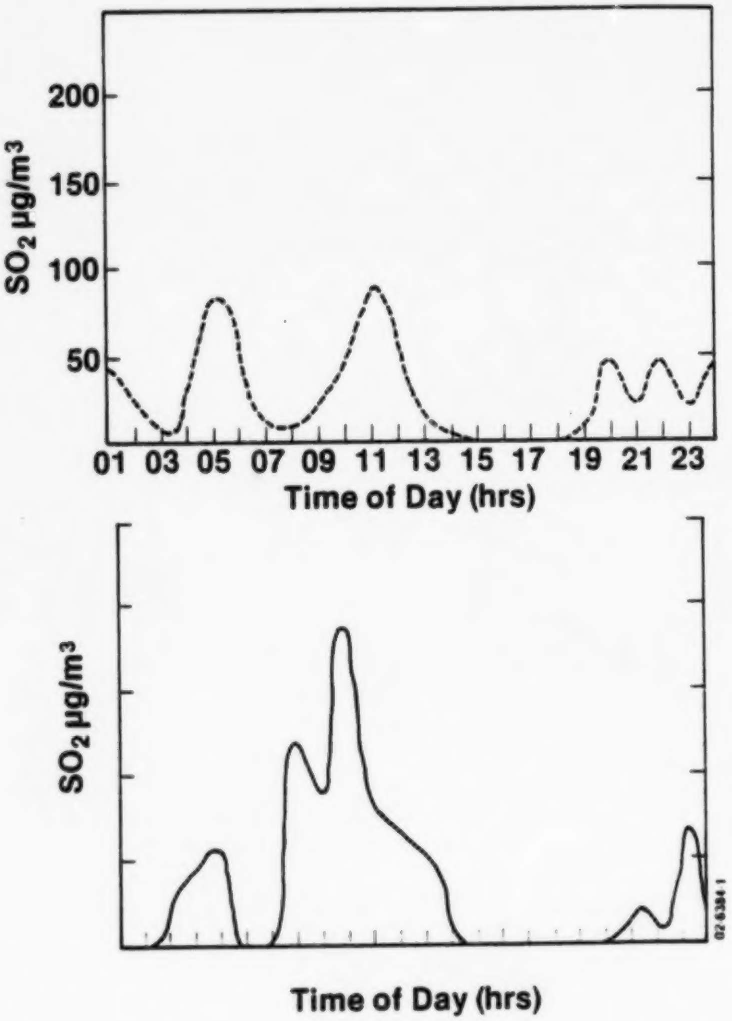

Figure 57. Diurnal Variations of SO$_2$ Measurements Site 19, September 27, 1978 and Site 22, October 8, 1978 (Houston Aerosol Characterization Study, 1978)

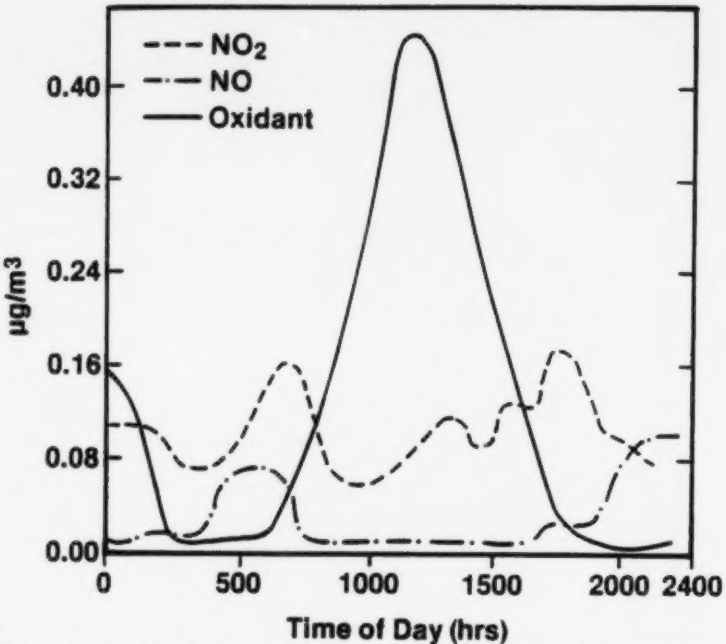

Figure 58. Diurnal Variation of Some Primary and Secondary Pollutants in Pasadena, California on July 25, 1973 (Findlayson and Pitts, Science 192:112, 1976).

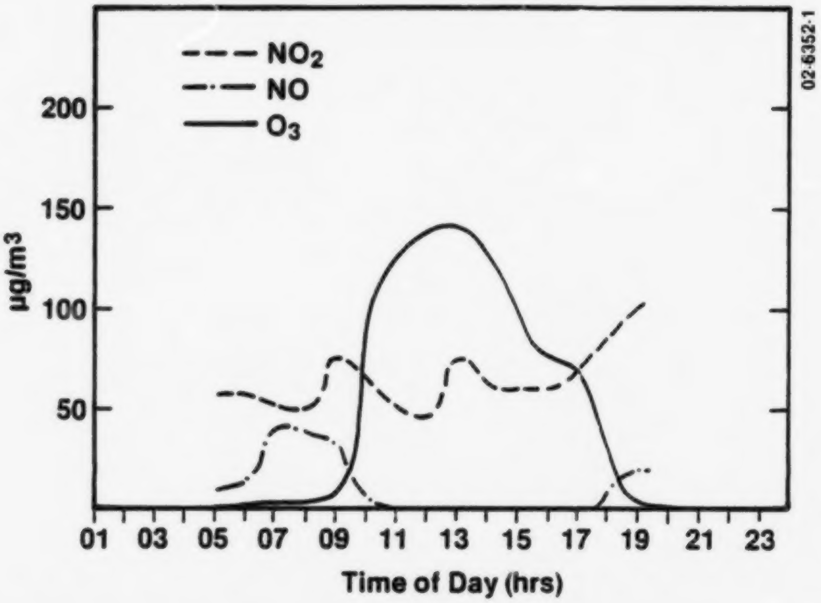

Figure 59. Diurnal Variation of Gaseous Constituents, Site 14, October 3, 1978 (Houston Aerosol Characterization Study, 1978).

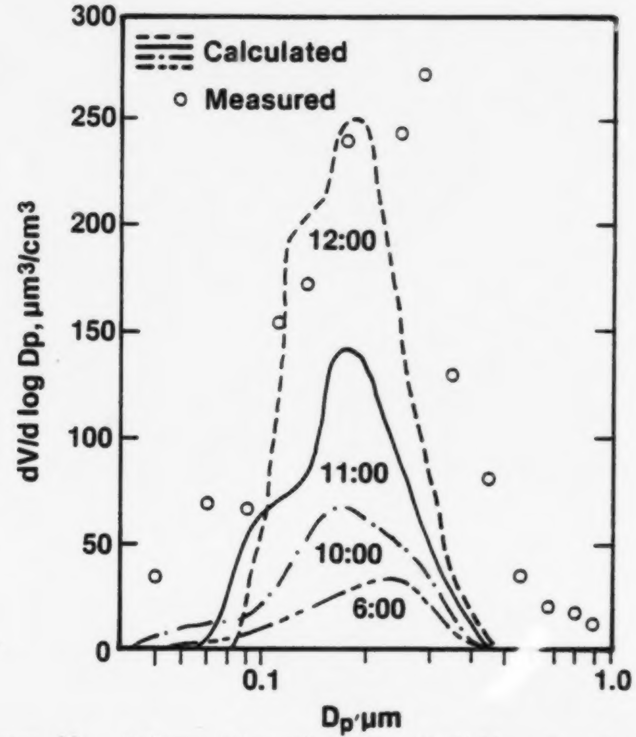

Figure 60. Volume Distribution of Midday Pasadena Aerosol on September 3, 1969. (White and Husan, J. Air Pollut. Contr. Assoc. 33:35, 1976).

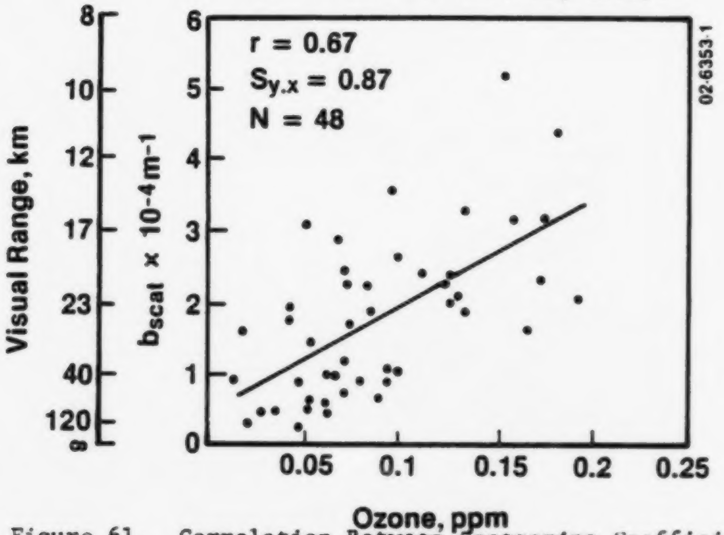

Figure 61. Correlation Between Scattering Coefficient for Visible Light and Daily Maximum Ozone Concentration Observed in New York City, during the NYAS 1976. (Leaderer, J. Air Pollut. Contr. Assoc. 28, 323, 1978).

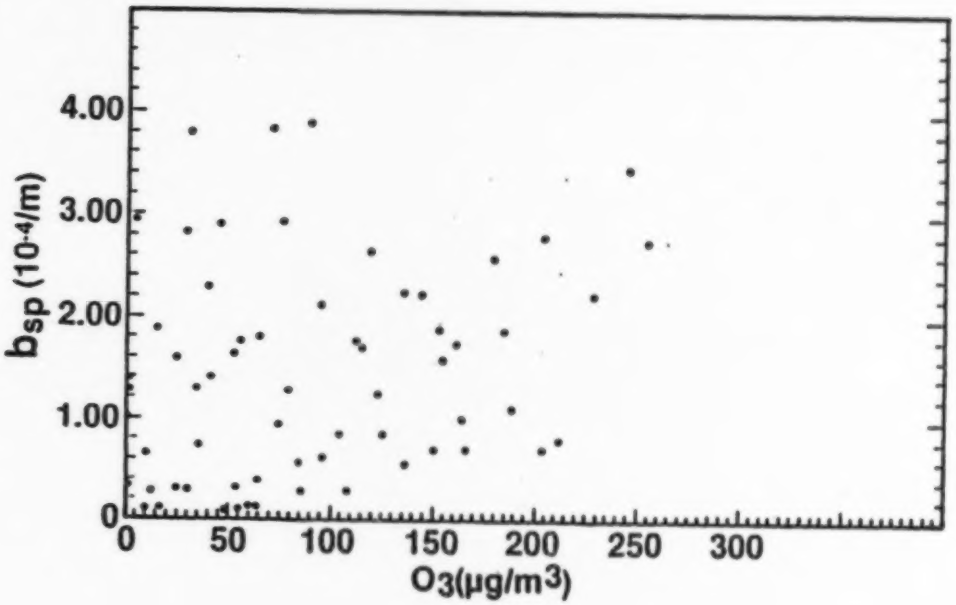

Figure 62. Scattergram of Light Scattering Measurements vs. Ozone Values (Houston Aerosol Characterization Study, 1978).

SECTION 7

LIST OF APPENDICES

The appendices listed below are not included in this volume of the report, but are available from Radian Corporation for a copying and handling fee. Contact the Library, Radian Corporation, 8501 Mopac Blvd., Austin, Texas, 78766 to request Volume II, containing Appendices B-K, and Volume III, containing Appendices L-O. Also, a magnetic tape containing the data from Appendix A is available for a nominal fee.

APPENDIX

PAGE

B Site Descriptions and Photographs of Sites for Monitoring Stations 1
C Experimentation Design for Houston Aerosol Study 38
D Meteorological and Gaseous Data Processing Algorithms 87
E Aerosols Data Processing Algorithms 94
F Calibration Procedures 96
G ADS Operating Procedures 116
H Radian's Filter Cleaning Procedure 166
I RTI Filter Handling Procedures 181
J Pibal Data Processing Algorithms 190
K Trailer Checklist 196
L Data Summary: Trailer 28 Continuous Data 1
M Data Summary: Trailer 28 Aerosol Data 30
N Data Summary: AQML Continuous Data 152
O Data Summary: AQML Aerosol Data 165

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APPENDIX A

HACS ARCHIVAL DATA TAPE SPECIFICATIONS

The Radian HACS archival data tape contains 17 files and approximately 10 million bytes. The tape contains all aerosol, meteorological, and gaseous pollutant data collected by Radian, the aerosol and gaseous pollutant data collected by EMI, and most of the tethersonde data collected by EQR.

The tape contains both raw and reduced data. All data are recorded as 80 column card image records, ASCII, and blocked 12 or 20 logical records per physical tape record. Files 14-17 are blocked 12, while the rest are blocked 20. The last physical tape record of each file is not padded and, therefore, may be short.

TAPE CONTENTS

The tape file contents are as follows:

File	Contents
1	Trailer 28 OPC raw data
2	Trailer 28 EAA raw data
3	Trailer 28 CNC and Nephelometer data
4	Trailer 28 EAA reduced data
5	Trailer 28 OPC reduced data
6	Trailer 28 Microbarograph data
7	Suspended Particulate data
8	Pibal data
9	Tethersonde data
10	AQML OPC raw data
11	AQML EAA raw data
12	AQML EAA reduced data
13	AQML OPC reduced data
14	Trailer 28 continuous data, September
15	Trailer 28 continuous data, October
16	AQML continuous data, September
17	AQML continuous data, October

File 1: Trailer 28 OPC Raw Data

Each OPC observation generated 21 numbers, and the values are recorded in 4 card image records. Each record is divided into an identification field in columns 1-20, and data fields in columns 21-80. The contents of the identification field are:

Columns	Contents
1-3	Constant "HAA"
4	Constant Blank
5-10	Data, YYMMDD
11-14	Time, HHMM
15-16	Constant Blank
17-18	Site number
19	Constant "P"
20	Card sequence number

The remainder of each card is composed of six 10-column fields. Of the 21 data values for each OPC observation, the first 19 values represent the number of particles in each bin, the first value being for the smallest sized particle, and the 19th value being for the largest particle size. (Note that the 19th value is the first value on the 4th card). The 20th value is the duration of the observation, in minutes, and the 21st value is the "dead time correction factor."

File 2: Trailer 28 EAA Raw Data

Each EAA observation generated 11 data values, all of which are stored on a single record. Each record is divided into an identification field and data fields similar to the OPC data except that the data are recorded as twelve 5-character fields. The data values consist of 10 delta voltages, in volts, and the 11th value is the residual voltage. Later in the file, a 12th value is present on each record. When this value is present, the 11 preceding values must be multiplied by the 12th value to obtain the proper voltages. (This format was changed during the study to simplify the coder's job).

File 3: Trailer 28 CNC and Nephelometer Data

Each record contains one observation from the CNC, the unheated nephelometer, and the heated nephelometer, in that order. As before, the first 20 columns are identification information. The data are recorded in three fields of 10 characters each. The units are #/CC, /M, and /M for the CNC, unheated nephelometer, and heated nephelometer, respectively. A value of 0 represents no data.

File 4: Trailer 28 Reduced EAA Data

Ten minute averages of the raw EAA data were formed and then reduced, creating 7 records. Each record is divided into an identification field and data field described above. The reduced data consist of 10 dN/dlogD values, 10 dS/dlogD values, and 10 dV/dlogD values. Additionally, since these data were reduced using the University of Minnesota χ^2 minimization technique, the resulting parameters ($\overline{X}_1$, σ_1, $\overline{X}_2$, σ_2, FRC_1) and the resulting χ^2 values are also recorded. These 4 types of data can be identified by the occurrence of the letters F, G, H, or X, respectively, in column 19 of the data records. The units for the reduced data are #/CC, μm^2/CC, and μm^2/CC, respectively.

File 5: Trailer 28 Reduced OPC Data

Each OPC observation resulted in 12 output records consisting of 19 dN/dlogD values, 19 dS/dlogD values, and 19 dV/dlogD values in the same units as the EAA reduced data (above). These types of data values can be identified by the occurrence of the letters Q, R, and S in column 19.

File 6: Trailer 28 Microbarograph Data

The microbarograph records are divided into an identification field and six 10-column data fields. Each 10-column data field is subdivided into a two digit side code and a five character pressure field. The time contained in the identification field is the ending time of the first pressure value of the record. Each subsequent pressure value represents the pressure at the next hour. Pressure value units are inches of mercury. A missing value is represented by a zero site.

File 7: Suspended Particulate Data

Particulate records are divided into an identification field and 12 data fields. The data values on the record represent the mass loading, in micrograms per cubic meter, over a twelve hour averaging period. For the twelve data fields, the site of each datum is implicit in the position. The first value on each record was taken at Site 1, the second value at Site 2, the third value at Site 12, the fourth value at Site 13, the fifth value at Site 14, the sixth value at Site 17, the seventh value at Site 18, the eighth value at Site 19, the ninth value at Site 20, the tenth value at Site 21, the eleventh value at Site 22, and the twelfth value at Site 23. Missing data are indicated by blank data fields. The beginning time of each experiment is contained in columns 11-14 and the ending time is contained in columns 15-18.

File 8: Pibal Data

Pibal data records are divided into an identification field and data fields similar to the previously discussed data. There are four types of data records, and they can be identified by the record type in Column 15. The four types are Header (H), Angle (A), Reduced (R), and Temperature (T). The data from each pibal release always begins with a Header record. The data field for that record contains descriptive text. The rest of the data for each release will contain one or more Angle cards and one or more Reduced cards and may contain one or more Temperature cards, depending on whether the release included a Temperaturesonde. The time contained in the identification field is the time of the balloon release.

Angle and Reduced records contain six 10-column fields which are subdivided into two 5-column fields. The data items on Angle cards are the azimuthal and elevation angles recorded by the theodolite operators, and the units are degrees. The values on the Reduced records are the wind speed and wind direction; the wind speed is in meters per second and the wind direction is in degrees from the direction in which the wind is blowing, relative to north. For these two types of records, the first number pair is the data at the end of the first 30 seconds ascent. The second number is the data at the end of 60 seconds, etc. The temperature data field is divided into twelve 5-column fields. The values recorded are the temperature at the corresponding heights, in degrees Celsius. The first value is the temperature at the surface, the second value is the temperature at the 30-second height, and the third value is the temperature at the 60-second height, etc.

The site is recorded in Column 18 of each record. Site 1 corresponds to the Radian-Houston Office, while Site 2 corresponds to Pearland.

The sort of these records from major to minor fields is date, site, time, and finally record type (in the order H, A, R, and T).

File 9: EQR Tethersonde Data

The EQR Tethersonde data was received in a printed output format. Each Tethersonde run begins with a card containing the letters "RUN" in Columns 21-23. The rest of the details can be obtained from printed sample.

File 10: AQML OPC Raw Data

The EMI OPC raw data format is identical to the Trailer 28 OPC raw data, File 1 (above), except that the month, day, hour, and minute fields may contain leading blanks instead of leading zeros.

File 11: AQML EAA Raw Data

These data are physically similar to the Trailer 28 EAA raw data (File 2 above). The values recorded on these records are the ten delta voltages, in millivolts. The residual voltage was not recorded.

File 12: AQML EAA Reduced Data

The format of these data records is identical to the Trailer 28 EAA reduced data (File 4), with the exception that type "X" records are not present because the University of Minnesota Data Reduction Technique was not used.

File 13: AQML Reduced OPC Data

These data are identical to the Trailer 28 reduced OPC data (File 5).

File 14: Trailer 28 Continuous Data, September

Trailer 28 data consist of five-minute averages of 13 parameters. The first 14 columns of each record are identification. The date is in Columns 5-10, and the time is in Columns 11-14. The time shown is the time at the start of the five-minute period. The data are recorded in thirteen 5-column fields. The order and units of the data are as follows:

Parameter	Description and Units
1 (Columns 15-19)	NO_x, PPB
2 (Columns 20-24)	NO, PPB
3 (etc.)	SO_2, PPB
4	Wind speed, miles per hour
5	Wind direction, degrees
6	Dew point, degrees Fahrenheit
7	Trailer (inside) temperature, degrees Fahrenheit
8	Outside temperature, degrees Fahrenheit
9	Pyranometer, hundredths of langleys per minute
10	UV radiometer, thousandths of langleys per minute
11	Line voltage, volts
12	Ozone, PPB
13	Wind direction standard deviation, degrees

A missing datum is indicated by a blank sub-field.

File 15: Trailer 28 Continuous Data, October

The format is identical to File 14.

File 16: AQML Continuous Data, September

The format of these data is identical to the Trailer 28 continuous data. The contents and units of the data fields are as follows:

Parameter	Contents, Units
1	Ozone (Dasibi), PPB
2	Ozone (Bendix), PPB
3	NO_x, PPB
4	NO, PPB
5	NO_2, PPB
6	SO_2, PPB
7	CO, PPM
8	Nephelometer, 10^{-2}/m
9	Radiometer, hundredths of langleys per minute

File 17: AQML Continuous Data, October

The format is identical to File 16.

```
HAA 7809160626  13P1 .3923E 07 .2191E 07 .1228E 07 .6021E 06 .3008E 06 .1619E 06
HAA 7809160626  13P2 .1033E 06 .8193E 05 .7018E 05 .6585E 05 .5414E 05 .2870E 05
HAA 7809160626  13P3 .2146E 05 .1448E 05 .7962E 04 .3739E 04 .1541E 04 .6548E 03
HAA 7809160626  13P4 .2578E 03        10.       1.06
HAA 7809160637  13P1 .4044E 07 .2504E 07 .1533E 07 .8107E 06 .4195E 06 .2232E 06
HAA 7809160637  13P2 .1352E 06 .9691E 05 .7737E 05 .7000E 05 .5611E 05 .2890E 05
HAA 7809160637  13P3 .2012E 05 .1314E 05 .7334E 04 .3152E 04 .1367E 04 .4829E 03
HAA 7809160637  13P4 .1910E 03        10.       1.06
HAA 7809160647  13P1 .3949E 07 .2294E 07 .1307E 07 .6431E 06 .3176E 06 .1657E 06
HAA 7809160647  13P2 .1019E 06 .7543E 05 .6082E 05 .5465E 05 .4362E 05 .2335E 05
HAA 7809160647  13P3 .1696E 05 .1106E 05 .6383E 04 .2897E 04 .1271E 04 .5288E 03
HAA 7809160647  13P4 .1547E 03        10.       1.06
HAA 7809160658  13P1 .4013E 07 .2433E 07 .1463E 07 .7672E 06 .3949E 06 .2041E 06
HAA 7809160658  13P2 .1178E 06 .8188E 05 .6474E 05 .5954E 05 .4899E 05 .2575E 05
HAA 7809160658  13P3 .1910E 05 .1309E 05 .8249E 04 .4575E 04 .2219E 04 .9262E 03
HAA 7809160658  13P4 .2788E 03        10.       1.11
HAA 7809160708  13P1 .3719E 07 .2097E 07 .1175E 07 .5766E 06 .3036E 06 .1910E 06
HAA 7809160708  13P2 .1522E 06 .1499E 06 .1648E 06 .1882E 06 .1557E 06 .7101E 05
HAA 7809160708  13P3 .4495E 05 .3153E 05 .2225E 05 .1266E 05 .5851E 04 .2310E 04
HAA 7809160708  13P4 .7506E 03        10        1.11
HAA 7809160719  13P1 .5101E 07 .3294E 07 .2017E 07 .1017E 07 .4720E 06 .2101E 06
HAA 7809160719  13P2 .1067E 06 .7065E 05 .5777E 05 .5448E 05 .4251E 05 .2094E 05
HAA 7809160719  13P3 .1435E 05 .8973E 04 .4895E 04 .2100E 04 .8763E 03 .3094E 03
HAA 7809160719  13P4 .1089E 03        10        1.11
HAA 7809160730  13P1 .4853E 07 .3722E 07 .2729E 07 .1654E 07 .8830E 06 .4038E 06
HAA 7809160730  13P2 .1739E 06 .8994E 05 .6438E 05 .5933E 05 .4414E 05 .2026E 05
HAA 7809160730  13P3 .1318E 05 .7869E 04 .4144E 04 .1771E 04 .6565E 03 .2272E 03
HAA 7809160730  13P4 .7066E 02        10.       1.17
HAA 7809160741  13P1 .4673E 07 .3702E 07 .2840E 07 .1800E 07 .1007E 07 .4748E 06
HAA 7809160741  13P2 .2028E 06 .9673E 05 .6637E 05 .6089E 05 .4387E 05 .1940E 05
HAA 7809160741  13P3 .1239E 05 .7254E 04 .3560E 04 .1510E 04 .5462E 03 .1585E 03
HAA 7809160741  13P4 .4584E 02        10        1.17
HAA 7809160752  13P1 .5141E 07 .3797E 07 .2649E 07 .1494E 07 .7265E 06 .2992E 06
HAA 7809160752  13P2 .1240E 06 .7359E 05 .6378E 05 .6202E 05 .4139E 05 .1821E 05
HAA 7809160752  13P3 .1205E 05 .6932E 04 .3550E 04 .1353E 04 .5385E 03 .2043E 03
HAA 7809160752  13P4 .4584E 02        10.       1.22
HAA 7809160802  13P1 .5072E 07 .3800E 07 .2695E 07 .1542E 07 .7616E 06 .3155E 06
HAA 7809160802  13P2 .1283E 06 .7570E 05 .6511E 05 .6286E 05 .4121E 05 .1756E 05
HAA 7809160802  13P3 .1125E 05 .6609E 04 .3365E 04 .1355E 04 .4238E 03 .1413E 03
HAA 7809160802  13P4 .5730E 02        10.       1.22
HAA 7809160813  13P1 .4809E 07 .3610E 07 .2601E 07 .1550E 07 .8189E 06 .3743E 06
HAA 7809160813  13P2 .1663E 06 .9092E 05 .6976E 05 .6718E 05 .4788E 05 .2089E 05
HAA 7809160813  13P3 .1338E 05 .7621E 04 .3591E 04 .1375E 04 .5232E 03 .1757E 03
HAA 7809160813  13P4 .4202E 02        10        1.17
HAA 7809160824  13P1 .4389E 07 .2819E 07 .1728E 07 .8783E 06 .4211E 06 .2007E 06
```

File 1   Trailer 28 OPC raw data

```
HAA 7809160600  13E  .0   .0   .015 .035 .020 .035 .050 .035 .015 .005 .010
HAA 7809160602  13E  .0   .0   .015 .040 .020 .035 .050 .035 .015 .005 .010
HAA 7809160604  13E  .0   .0   .015 .035 .020 .035 .05  .035 .015 .005 .010
HAA 7809160606  13E  .0   .0   .015 .035 .015 .035 .045 .035 .015 .005 .010
HAA 7809160608  13E  .0   .0   .015 .04  .020 .035 .045 .035 .015 .005 .010
HAA 7809160610  13E  .0   .0   .015 .04  .020 .035 .05  .035 .015 .005 .010
HAA 7809160612  13E  .0   .0   .015 .04  .02  .035 .05  .035 .015 .005 .010
HAA 7809160614  13E  .0   .0   .015 .035 .02  .035 .05  .035 .015 .005 .010
HAA 7809160616  13E  .0   .0   .015 .035 .02  .03  .05  .035 .015 .005 .010
HAA 7809160618  13E  .0   .0   .015 .035 .02  .03  .045 .035 .015 .005 .010
HAA 7809160620  13E  .0   .0   .015 .035 .02  .03  .045 .035 .015 .005 .010
HAA 7809160622  13E  .0   .0   .015 .035 .02  .03  .05  .035 .015 .005 .010
HAA 7809160624  13E  .0   .0   .015 .035 .02  .03  .05  .035 .015 .005 .010
HAA 7809160626  13E  .0   .0   .015 .035 .02  .03  .05  .035 .015 .005 .010
HAA 7809160628  13E  .0   .0   .015 .035 .02  .03  .05  .035 .015 .005 .010
HAA 7809160630  13E  .0   .0   .015 .035 .02  .03  .05  .035 .015 .005 .010
HAA 7809160632  13E  .0   .0   .015 .035 .02  .035 .05  .035 .015 .005 .010
HAA 7809160634  13E  .0   .0   .015 .035 .02  .035 .05  .035 .015 .005 .010
HAA 7809160636  13E  .0   .0   .0   .035 .02  .035 .045 .035 .015 .005 .010
HAA 7809160638  13E  .0   .0   .01  .035 .015 .035 .045 .03  .015 .005 .010
HAA 7809160640  13E  .0   .0   .015 .035 .02  .035 .045 .03  .015 .005 .010
HAA 7809160642  13E  .0   .0   .015 .035 .02  .035 .045 .03  .01  .005 .010
HAA 7809160644  13E  .0   .0   .01  .035 .02  .035 .045 .025 .01  .005 .010
HAA 7809160646  13E  .0   .0   .01  .040 .015 .035 .05  .025 .01  .005 .010
HAA 7809160648  13E  .0   .0   .01  .040 .015 .035 .05  .025 .01  .005 .010
HAA 7809160650  13E  .0   .0   .015 .035 .02  .04  .055 .025 .01  .005 .010
HAA 7809160652  13E  .0   .0   .015 .040 .02  .04  .055 .025 .01  .005 .010
HAA 7809160654  13E  .0   .0   .015 .035 .02  .035 .05  .025 .01  .005 .010
HAA 7809160656  13E  .0   .0   .015 .035 .02  .035 .05  .025 .01  .005 .010
HAA 7809160658  13E  .0   .0   .015 .035 .02  .035 .05  .025 .01  .005 .010
HAA 7809160700  13E  .0   .0   .015 .035 .02  .035 .05  .025 .01  .005 .010
HAA 7809160702  13E  .0   .0   .015 .035 .02  .035 .05  .025 .01  .005 .010
HAA 7809160704  13E  .0   .0   .015 .035 .02  .035 .05  .025 .01  .005 .010
HAA 7809160706  13E  .0   .0   .015 .035 .02  .035 .05  .025 .01  .005 .010
HAA 7809160708  13E  .0   .0   .015 .035 .02  .035 .05  .025 .01  .005 .010
HAA 7809160710  13E  .0   .0   .02  .045 .015 .035 .04  .03  .015 .01  .010
HAA 7809160712  13E  .0   .0   .02  .04  .015 .035 .045 .03  .015 .01  .010
HAA 7809160714  13E  .0   .0   .02  .04  .015 .035 .04  .03  .015 .01  .010
HAA 7809160716  13E  .0   .0   .02  .045 .015 .03  .04  .03  .015 .01  .010
HAA 7809160718  13E  .0   .0   .02  .04  .015 .03  .04  .03  .015 .01  .010
HAA 7809160720  13E  .0   .0   .02  .04  .015 .035 .04  .03  .015 .01  .010
HAA 7809160722  13E  .0   .0   .02  .04  .015 .035 .045 .03  .015 .01  .010
HAA 7809160724  13E  .0   .0   .02  .04  .015 .035 .045 .03  .015 .01  .010
HAA 7809160726  13E  .0   .0   .02  .045 .015 .035 .045 .03  .015 .01  .010
HAA 7809160728  13E  .0   .0   .02  .04  .015 .035 .045 .03  .015 .01  .010
```

File 2 Trailer 28 EAA raw data

```
HAA 780916 610  13M  .2800E  5 .0000E  0 .0000E  0
HAA 780916 615  13M  .2750E  5 .0000E  0 .0000E  0
HAA 780916 620  13M  .2700E  5 .0000E  0 .0000E  0
HAA 780916 625  13M  .2700E  5 .0000E  0 .0000E  0
HAA 780916 630  13M  .2600E  5 .0000E  0 .0000E  0
HAA 780916 635  13M  .2800E  5 .0000E  0 .0000E  0
HAA 780916 640  13M  .2600E  5 .0000E  0 .0000E  0
HAA 780916 645  13M  .2500E  5 .0000E  0 .0000E  0
HAA 780916 650  13M  .2600E  5 .0000E  0 .0000E  0
HAA 780916 655  13M  .2700E  5 .0000E  0 .0000E  0
HAA 780916 7 0  13M  .2800E  5 .0000E  0 .0000E  0
HAA 780916 7 5  13M  .3300E  5 .0000E  0 .0000E  0
HAA 780916 710  13M  .3400E  5 .0000E  0 .0000E  0
HAA 780916 715  13M  .3500E  5 .0000E  0 .0000E  0
HAA 780916 720  13M  .3500E  5 .0000E  0 .0000E  0
HAA 780916 725  13M  .3300E  5 .0000E  0 .0000E  0
HAA 780916 730  13M  .3000E  5 .0000E  0 .0000E  0
HAA 780916 735  13M  .3100E  5 .0000E  0 .0000E  0
HAA 780916 740  13M  .3200E  5 .0000E  0 .0000E  0
HAA 780916 745  13M  .3000E  5 .0000E  0 .0000E  0
HAA 780916 750  13M  .3100E  5 .0000E  0 .0000E  0
HAA 780916 755  13M  .3300E  5 .0000E  0 .0000E  0
HAA 780916 8 0  13M  .3400E  5 .0000E  0 .0000E  0
HAA 780916 8 5  13M  .4200E  5 .0000E  0 .0000E  0
HAA 780916 810  13M  .3400E  5 .0000E  0 .0000E  0
HAA 780916 820  13M  .3700E  5 .0000E  0 .0000E  0
HAA 780916 825  13M  .3700E  5 .0000E  0 .0000E  0
HAA 780916 830  13M  .4200E  5 .0000E  0 .0000E  0
HAA 780916 835  13M  .4400E  5 .0000E  0 .0000E  0
HAA 780916 840  13M  .3800E  5 .0000E  0 .0000E  0
HAA 780916 845  13M  .4000E  5 .0000E  0 .0000E  0
HAA 780916 850  13M  .3700E  5 .0000E  0 .0000E  0
HAA 780916 855  13M  .3500E  5 .0000E  0 .0000E  0
HAA 780916 9 0  13M  .7500E  5 .0000E  0 .0000E  0
HAA 780916 9 5  13M  .3500E  5 .0000E  0 .0000E  0
HAA 780916 910  13M  .3300E  5 .0000E  0 .0000E  0
HAA 780916 915  13M  .6500E  5 .0000E  0 .0000E  0
HAA 780916 920  13M  .3200E  5 .0000E  0 .0000E  0
HAA 780916 925  13M  .6500E  5 .0000E  0 .0000E  0
HAA 780916 930  13M  .3300E  5 .0000E  0 .0000E  0
HAA 780916 935  13M  .3500E  5 .0000E  0 .0000E  0
HAA 780916 940  13M  .3400E  5 .0000E  0 .0000E  0
HAA 780916 945  13M  .3300E  5 .0000E  0 .0000E  0
HAA 780916 950  13M  .2800E  5 .0000E  0 .0000E  0
HAA 780916 955  13M  .2800E  5 .0000E  0 .0000E  0
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File 3   Trailer 28 CNC and Nephelometer data

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HAA1780916 6 0  13F2 .4907E 04 .2058E 04 .4558E 03 .7151E 02
HAA1780916 6 0  1301 .0000E 00 .0000E 00 .1309E 02 .3163E 02 .6711E 02 .1233E 03
HAA1780916 6 0  1302 .2668E 03 .3447E 03 .2353E 03 .1138E 03
HAA1780916 6 0  13H1 .0000E 00 .0000E 00 .3168E-01 .1344E 00 .5009E 00 .1616E 01
HAA1780916 6 0  13H2 .6139E 01 .1392E 02 .1668E 02 .1416E 02
HAA 780916 6 0  13X  .1756E-01 .3279E 01 .1843E 01 .1597E 01 .1000E 01 .3744E-01
HAA5780916 610  13F1 .0000E 00 .0000E 00 .2173E 05 .1856E 05 .1117E 05 .7018E 04
HAA5780916 610  13F2 .4710E 04 .2063E 04 .4552E 03 .7066E 02
HAA5780916 610  1301 .0000E 00 .0000E 00 .1310E 02 .3448E 02 .6390E 02 .1237E 03
HAA5780916 610  1302 .2555E 03 .3448E 03 .2344E 03 .1122E 03
HAA5780916 610  13H1 .0000E 00 .0000E 00 .3168E-01 .1464E 00 .4766E 00 .1619E 01
HAA5780916 610  13H2 .5874E 01 .1391E 02 .1660E 02 .1394E 02
HAA 780916 610  13X  .1701E-01 .3268E 01 .1857E 01 .1715E 01 .1000E 01 .3699E-01
HAA5780916 620  13F1 .0000E 00 .0000E 00 .2174E 05 .1756E 05 .1174E 05 .6396E 04
HAA5780916 620  13F2 .4708E 04 .2057E 04 .4557E 03 .7162E 02
HAA5780916 620  1301 .0000E 00 .0000E 00 .1310E 02 .3262E 02 .6718E 02 .1128E 03
HAA5780916 620  1302 .2558E 03 .3445E 03 .2352E 03 .1140E 03
HAA5780916 620  13H1 .0000E 00 .0000E 00 .3168E-01 .1386E 00 .5012E 00 .1478E 01
HAA5780916 620  13H2 .5885E 01 .1391E 02 .1667E 02 .1418E 02
HAA 780916 620  13X  .1701E-01 .3300E 01 .1857E 01 .1812E 01 .1000E 01 .4140E-01
HAA5780916 630  13F1 .0000E 00 .0000E 00 .2174E 05 .1707E 05 .1174E 05 .5997E 04
HAA5780916 630  13F2 .4904E 04 .2057E 04 .4557E 03 .7163E 02
HAA5780916 630  1301 .0000E 00 .0000E 00 .1310E 02 .3172E 02 .6718E 02 .1058E 03
HAA5780916 630  1302 .2665E 03 .3445E 03 .2352E 03 .1140E 03
HAA5780916 630  13H1 .0000E 00 .0000E 00 .3168E-01 .1347E 00 .5012E 00 .1386E 01
HAA5780916 630  13H2 .6130E 01 .1391E 02 .1667E 02 .1419E 02
HAA 780916 630  13X  .1701E-01 .3300E 01 .1857E 01 .1942E 01 .1000E 01 .4941E-01
HAA5780916 640  13F1 .0000E 00 .0000E 00 .1594E 05 .1705E 05 .1113E 05 .6974E 04
HAA5780916 640  13F2 .4607E 04 .1934E 04 .4560E 03 .7253E 02
HAA5780916 640  1301 .0000E 00 .0000E 00 .9608E 01 .3168E 02 .6374E 02 .1231E 03
HAA5780916 640  1302 .2508E 03 .3244E 03 .2359E 03 .1158E 03
HAA5780916 640  13H1 .0000E 00 .0000E 00 .2323E-01 .1346E 00 .4757E 00 .1614E 01
HAA5780916 640  13H2 .5773E 01 .1311E 02 .1674E 02 .1442E 02
HAA 780916 640  13X  .1701E-01 .3333E 01 .1857E 01 .2040E 01 .1000E 01 .2868E-01
HAA5780916 650  13F1 .0000E 00 .0000E 00 .1747E 05 .1827E 05 .1066E 05 .7269E 04
HAA5780916 650  13F2 .4801E 04 .1528E 04 .2946E 03 .6738E 02
HAA5780916 650  1301 .0000E 00 .0000E 00 .1050E 02 .3383E 02 .6077E 02 .1277E 03
HAA5780916 650  1302 .2597E 03 .2548E 03 .1514E 03 .1078E 03
HAA5780916 650  13H1 .0000E 00 .0000E 00 .2534E-01 .1435E 00 .4526E 00 .1670E 01
HAA5780916 650  13H2 .5962E 01 .1026E 02 .1071E 02 .1346E 02
HAA 780916 650  13X  .1584E-01 .3276E 01 .1905E 01 .2181E 01 .9997E 00 .3894E-01
HAA5780916 7 0  13F1 .0000E 00 .0000E 00 .2188E 05 .1785E 05 .1187E 05 .7284E 04
HAA5780916 7 0  13F2 .4993E 04 .1473E 04 .2985E 03 .6830E 02
HAA5780916 7 0  1301 .0000E 00 .0000E 00 .1313E 02 .3301E 02 .6761E 02 .1278E 03
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File 4 Trailer 28 EAA reduced data

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HAA 7809160626  13D3 .3856E 01 .2602E 01 .1431E 01 .6718E 00 .2769E 00 .1177E 00
HAA 7809160626  13D4 .4632E-01
HAA 7809160626  13R1 .2215E 03 .1815E 03 .1493E 03 .1075E 03 .7881E 02 .6226E 02
HAA 7809160626  13R2 .5831E 02 .6788E 02 .8535E 02 .1175E 03 .1419E 03 .1104E 03
HAA 7809160626  13R3 .1211E 03 .1200E 03 .9683E 02 .6674E 02 .4038E 02 .2518E 02
HAA 7809160626  13R4 .1455E 02
HAA 7809160626  13B1 .1167E 02 .1159E 02 .1155E 02 .1007E 02 .8949E 01 .8566E 01
HAA 7809160626  13B2 .9719E 01 .1371E 02 .2088E 02 .3484E 02 .5094E 02 .4802E 02
HAA 7809160626  13B3 .6385E 02 .7661E 02 .7491E 02 .6255E 02 .4585E 02 .3464E 02
HAA 7809160626  13B4 .2425E 02
HAA 7809160637  13D1 .7266E 03 .4499E 03 .2754E 03 .1457E 03 .7538E 02 .4010E 02
HAA 7809160637  13D2 .2429E 02 .1741E 02 .1390E 02 .1258E 02 .1008E 02 .5193E 01
HAA 7809160637  13D3 .3615E 01 .2361E 01 .1318E 01 .5664E 00 .2456E 00 .8677E-01
HAA 7809160637  13D4 .3432E-01
HAA 7809160637  13R1 .2283E 03 .2075E 03 .1864E 03 .1447E 03 .1099E 03 .8584E 02
HAA 7809160637  13R2 .7632E 02 .8030E 02 .9409E 02 .1250E 03 .1470E 03 .1111E 03
HAA 7809160637  13R3 .1136E 03 .1089E 03 .8919E 02 .5626E 02 .3582E 02 .1857E 02
HAA 7809160637  13R4 .1078E 02
HAA 7809160637  13B1 .1203E 02 .1325E 02 .1442E 02 .1356E 02 .1248E 02 .1181E 02
HAA 7809160637  13B2 .1272E 02 .1621E 02 .2302E 02 .3703E 02 .5279E 02 .4835E 02
HAA 7809160637  13B3 .5986E 02 .6952E 02 .6900E 02 .5273E 02 .4067E 02 .2555E 02
HAA 7809160637  13B4 .1797E 02
HAA 7809160647  13D1 .7096E 03 .4122E 03 .2348E 03 .1156E 03 .5707E 02 .2977E 02
HAA 7809160647  13D2 .1831E 02 .1355E 02 .1093E 02 .9820E 01 .7838E 01 .4196E 01
HAA 7809160647  13D3 .3047E 01 .1987E 01 .1147E 01 .5205E 00 .2284E 00 .9501E-01
HAA 7809160647  13D4 .2780E-01
HAA 7809160647  13R1 .2229E 03 .1901E 03 .1590E 03 .1148E 03 .8322E 02 .6373E 02
HAA 7809160647  13R2 .5752E 02 .6250E 02 .7397E 02 .9755E 02 .1143E 03 .8980E 02
HAA 7809160647  13R3 .9574E 02 .9164E 02 .7763E 02 .5171E 02 .3330E 02 .2034E 02
HAA 7809160647  13R4 .8733E 01
HAA 7809160647  13B1 .1175E 02 .1214E 02 .1230E 02 .1076E 02 .9449E 01 .8767E 01
HAA 7809160647  13B2 .9587E 01 .1262E 02 .1809E 02 .2891E 02 .4104E 02 .3907E 02
HAA 7809160647  13B3 .5046E 02 .5851E 02 .6005E 02 .4847E 02 .3781E 02 .2798E 02
HAA 7809160647  13B4 .1455E 02
HAA 7809160658  13D1 .7551E 03 .4578E 03 .2753E 03 .1444E 03 .7430E 02 .3840E 02
HAA 7809160658  13D2 .2216E 02 .1541E 02 .1218E 02 .1120E 02 .9218E 01 .4845E 01
HAA 7809160658  13D3 .3594E 01 .2463E 01 .1552E 01 .8608E 00 .4175E 00 .1743E 00
HAA 7809160658  13D4 .5246E-01
HAA 7809160658  13R1 .2372E 03 .2111E 03 .1863E 03 .1434E 03 .1083E 03 .8220E 02
HAA 7809160658  13R2 .6963E 02 .7104E 02 .8245E 02 .1113E 03 .1344E 03 .1037E 03
HAA 7809160658  13R3 .1129E 03 .1136E 03 .1051E 03 .8552E 02 .6088E 02 .3730E 02
HAA 7809160658  13R4 .1648E 02
HAA 7809160658  13B1 .1250E 02 .1348E 02 .1441E 02 .1344E 02 .1230E 02 .1131E 02
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File 5   Trailer 28 OPC reduced data

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HAM 78 9141900       0  0.00   0  0.00   0  0.00  21 29.91  21 29.92  21 29.92
HAM 78 915 100      21 29.92  21 29.92  21 29.92  21 29.91  21 29.92  21 29.92
HAM 78 915 700      21 29.94  21 29.95  21 29.97  21 29.98  21 29.99  21 29.98
HAM 78 9151300      21 29.96  21 29.94   0  0.00   0  0.00   0  0.00   0  0.00
HAM 78 9151900       0  0.00   0  0.00   0  0.00  13 29.96  13 29.96  13 29.96
HAM 78 916 100      13 29.95  13 29.94  13 29.94  13 29.93  13 29.93  13 29.93
HAM 78 916 700      13 29.93  13 29.93  13 29.93  13 29.94  13 29.94  13 29.95
HAM 78 9161300      13 29.90  13 29.88  13 29.84  13 29.84  13 29.84  13 29.84
HAM 78 9161900      13 29.84  13 29.85  13 29.86  13 29.86  13 29.86  13 29.86
HAM 78 917 100      13 29.86  13 29.85  13 29.85  13 29.85  13 29.85  13 29.85
HAM 78 917 700      13 29.87  13 29.88  13 29.89  13 29.90  13 29.91  13 29.91
HAM 78 9171300      13 29.90  13 29.88  13 29.87  13 29.86  13 29.84  13 29.84
HAM 78 9171900       0  0.00   0  0.00   0  0.00  19 29.87  19 29.87  19 29.87
HAM 78 918 100      19 29.87  19 29.87  19 29.86  19 29.86  19 29.86  19 29.88
HAM 78 918 700      19 29.90  19 29.91  19 29.92  19 29.94  19 29.96  19 29.94
HAM 78 9181300      19 29.94  19 29.92  19 29.90  19 29.90  19 29.90  19 29.90
HAM 78 9181900      19 29.90  19 29.92  19 29.96  19 29.97  19 29.97  19 29.97
HAM 78 919 100      19 29.98  19 29.98  19 29.97  19 29.97  19 29.99  19 30.00
HAM 78 919 700      19 30.02  19 30.02  19 30.03  19 30.04  19 30.05  19 30.04
HAM 78 9191300      19 30.02  19 30.00  19 29.98  19 29.98  19 29.98  19 29.98
HAM 78 9191900       0  0.00   0  0.00  23 29.99  23 29.98  23 29.98  23 29.98
HAM 78 920 100      23 29.98  23 29.97  23 29.96  23 29.97  23 29.98  23 29.98
HAM 78 920 700      23 29.99  23 29.99  23 29.99  23 29.98  23 29.97  23 29.94
HAM 78 9201300      23 29.92  23 29.92   0  0.00  23 29.91  23 29.92  23 29.91
HAM 78 9201900      23 29.92  23 29.93  23 29.95  23 29.96  23 29.96  23 29.97
HAM 78 921 100      23 29.97  23 29.96  23 29.96  23 29.96  23 29.96  23 29.97
HAM 78 921 700      23 29.98  23 30.00  23 30.00  23 30.01  23 30.01  23 30.01
HAM 78 9211300      23 30.00  23 29.97  23 29.94  23 29.96  23 29.95  23 29.95
HAM 78 9211900      23 29.98  23 30.00  23 30.02  23 30.03  23 30.05  23 30.05
HAM 78 922 100      23 30.04  23 30.04  23 30.04  23 30.04  23 30.04  23 30.05
HAM 78 922 700      23 30.06  23 30.08  23 30.11  23 30.12  23 30.13  23 30.11
HAM 78 9221300      23 30.10  23 30.09  23 30.08  23 30.08  23 30.08  23 30.09
HAM 78 9221900      23 30.10  23 30.12  23 30.14  23 30.16  23 30.17  23 30.17
HAM 78 923 100      23 30.17  23 30.17  23 30.16  23 30.16  23 30.16  23 30.15
HAM 78 923 700      23 30.16  23 30.17  23 30.19  23 30.20  23 30.20  23 30.19
HAM 78 9231300      23 30.17  23 30.16  23 30.14  23 30.12  23 30.12  23 30.12
HAM 78 9231900      23 30.12  23 30.13  23 30.14  23 30.15  23 30.15  23 30.15
HAM 78 924 100      23 30.15  23 30.14  23 30.13  23 30.13  23 30.13  23 30.14
HAM 78 924 700      23 30.15  23 30.16  23 30.17  23 30.18  23 30.20  23 30.19
HAM 78 9241300      23 30.16  23 30.12  23 30.10  23 30.10  23 30.08  23 30.07
HAM 78 9241900      23 30.08  23 30.08  23 30.10  23 30.10  23 30.10  23 30.10
HAM 78 925 100      23 30.09  23 30.09  23 30.08  23 30.06  23 30.06  23 30.06
HAM 78 925 700      23 30.06  23 30.07  23 30.08  23 30.09  23 30.08  23 30.07
HAM 78 9251300      23 30.04  23 30.02  23 29.98  23 29.97  23 29.96  23 29.96
HAM 78 9251900      23 29.97  23 29.99  23 30.00  23 30.02  23 30.01  23 30.01
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File 6   Trailer 28 Microbarograph data

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HAP 7809150758H  1  PIBAL PLUB TBONDE
HAP 7809150758A 11   -1. 0 -1. 0163. 2 42. 1168. 5 38. 7172. 5 36. 6176. 6 35. 3180. 4 34. 1
HAP 7809150758A 21  183. 4 32. 9
HAP 7809150758R 11     4. 1163. 2 -1. 0 -1. 0   5. 6179. 3   5. 9186. 0   6. 2192. 7   6. 6196. 4
HAP 7809150758R 21     6. 8197. 4
HAP 7809150758T 11   28. 0 27. 4 27. 0 26. 9 26. 4 26. 0 25. 5 25. 0 24. 7 24. 0 23. 2 22. 9
HAP 7809150758T 21   22. 0 21. 0 21. 0 20. 4 20. 0 19. 7 19. 0 19. 0 18. 5 18. 0 17. 9 17. 0
HAP 7809150758T 31   16. 4 16. 0 15. 8 -1. 0 -1. 0 14. 0 13. 6 13. 0 12. 8
HAP 7809150900H  1  PIBAL RELEASE
HAP 7809150900A 11   -1. 0 -1. 0164. 1 30. 9164. 4 31. 3167. 1 30. 7172. 3 29. 7174. 7 29. 0
HAP 7809150900A 21  179. 1 28. 3181. 6 27. 8183. 4 27. 3185. 0 27. 0 -1. 0 -1. 0187. 5 26. 0
HAP 7809150900A 31  188. 1 25. 8188. 4 25. 5188. 5 25. 4188. 7 25. 3188. 6 25. 2188. 6 25. 2
HAP 7809150900A 41  188. 8 25. 2189. 1 25. 3189. 5 25. 4189. 9 25. 4190. 0 25. 6190. 1 25. 7
HAP 7809150900A 51  190. 3 26. 0190. 7 26. 3191. 1 26. 7191. 3 27. 1191. 6 27. 5191. 8 27. 8
HAP 7809150900A 61  192. 0 28. 1192. 1 28. 5
HAP 7809150900R 11     6. 3164. 1 -1. 0 -1. 0   5. 9170. 3   6. 8182. 7   7. 3187. 3   7. 5193. 4
HAP 7809150900R 21     7. 7199. 0   7. 6196. 4   7. 6196. 9 -1. 0 -1. 0   8. 1198. 0 -1. 0 -1. 0
HAP 7809150900R 31     7. 5193. 4   7. 4190. 9   7. 0190. 8   7. 1189. 3   6. 9187. 8   6. 6190. 6
HAP 7809150900R 41     6. 3194. 1   6. 0197. 2   6. 3198. 7   5. 9196. 1   5. 5192. 9   5. 0195. 0
HAP 7809150900R 51     4. 3202. 1   3. 9208. 5   3. 3206. 9   3. 1205. 5   3. 4204. 9   3. 6201. 9
HAP 7809150900R 61     3. 1200. 9   2. 7199. 1
HAP 7809151001H  1  PIBAL RELEASE
HAP 7809151001A 11  175. 5 45. 4175. 2 40. 0179. 2 38. 8181. 5 39. 7182. 9 37. 9183. 1 37. 4
HAP 7809151001A 21  186. 0 35. 4188. 2 33. 8190. 0 32. 4191. 1 31. 0191. 8 30. 0191. 9 29. 4
HAP 7809151001A 31  191. 8 29. 0191. 6 28. 9191. 4 28. 8
HAP 7809151001R 11     4. 5175. 2   4. 9180. 6   4. 2188. 1   4. 7188. 3   5. 2185. 7   5. 9192. 1
HAP 7809151001R 21     7. 0198. 3   7. 4199. 4   7. 9198. 7   8. 0197. 3   7. 4195. 0   7. 0191. 8
HAP 7809151001R 31     6. 4189. 9   6. 0188. 8   6. 0188. 6
HAP 7809151059H  1  PIBAL RELEASE
HAP 7809151059A 11   -1. 0 -1. 0190. 4 53. 1190. 5 54. 0191. 1 52. 8190. 9 50. 8 -1. 0 -1. 0
HAP 7809151059A 21  190. 5 45. 5192. 2 42. 8193. 5 40. 4194. 3 38. 3194. 9 36. 6195. 2 35. 8
HAP 7809151059A 31  194. 9 35. 4194. 4 35. 0194. 0 35. 0193. 1 34. 8192. 3 34. 5191. 6 34. 5
HAP 7809151059A 41  191. 1 34. 4190. 4 34. 3189. 6 34. 2188. 9 34. 4188. 4 34. 7188. 0 35. 0
HAP 7809151059A 51  188. 0 35. 4188. 1 35. 9188. 1 36. 3188. 0 36. 6187. 9 36. 9188. 0 37. 2
HAP 7809151059A 61  187. 8 37. 4187. 6 37. 8
HAP 7809151059R 11     2. 8190. 4 -1. 0 -1. 0   2. 6191. 8   3. 3191. 4 -1. 0 -1. 0   4. 8189. 9
HAP 7809151059R 21   -1. 0 -1. 0   6. 3199. 3   6. 8199. 0   7. 0198. 6   6. 4198. 3   5. 5194. 9
HAP 7809151059R 31     5. 3190. 2   4. 9188. 4   4. 8184. 0   5. 3180. 9   5. 1180. 3   4. 8180. 8
HAP 7809151059R 41     5. 0180. 0   5. 1176. 0   4. 6172. 9   3. 7171. 9   3. 4174. 0   3. 0180. 8
HAP 7809151059R 51     2. 5190. 3   2. 4190. 5   2. 7185. 9   2. 9183. 8   2. 8188. 0   3. 0185. 7
HAP 7809151059R 61     2. 7178. 1   2. 2175. 6
HAP 7809151300H  1  PIBAL PLUB TBONDE
HAP 7809151300A 11  180. 2 42. 5176. 2 41. 8170. 8 46. 1173. 2 59. 7173. 0 51. 2174. 7 51. 6
HAP 7809151300A 21  177. 2 50. 3180. 9 49. 1182. 3 48. 2185. 6 48. 2 -1. 0    . 0
HAP 7809151300R 11     4. 2176. 2   3. 3164. 9    . 2 86. 6   1. 9179. 1   4. 2176. 2   3. 1187. 0
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File 7   Suspended Particulate data

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HASP78091606001800   43   64        69
HASP78091618000600   46   42   21   38
HASP78091706001800        48   27
HASP78091806001800   52  117             65        68
HASP78092006001800                       62        52                  98
HASP78092106001800                                                     94
HASP78092306001800   82  152        78                                 98
HASP78092506001800  114  224                                          112
HASP78092606001800  127             60                    123
HASP78092618000600   88             58            125      85
HASP78092706001800  144             64            183     125
HASP78092718000600   57             41             70      51
HASP78092806001800   78             68            103      87
HASP78092906001800   94                           105  43              71
HASP78093006001800   70  136                       75                  70
HASP78100206001800  141  244                      105                 132
HASP78100306001800  133  250                  95        88
HASP78100406001800  113                       97        92
HASP78100506001800  108  238            109   91
HASP78100606001800             88            132        65
HASP78100706001800   53                                 52     71      99
HASP78100806001800  157                                             67 120
HASP78100906001800       183                                   86   54 118
HASP78101006001800       222                                        63 149
HASP78101018000600                                                  31
HASP78101106001800                                                  66  91
```

File 8 Pibal data

```
          RUN # 1   DATE=09/19/78   INI. TIME= 925      PAGE  1
                    INI. PRESSURE=1017.3MB

  TIME     HEIGHT     PRESSURE      TEMP      RH     SPEED    DIR.
            (M)         (MB)        (C)       (%)    (MPS)    (DEG)
          ________   __________   ________   _____   ______   ______
  0.65      10.52     1016.09      28.83      93.     3.04    181.7
  0.99      10.09     1016.14      29.03      94.     1.46    180.3
  1.65      15.40     1015.53      29.07      93.     3.70    191.2
  1.98      47.41     1011.86      28.91      93.     2.94    162.0
  2.31      77.48     1008.42      28.58      93.     3.90    154.4
  2.64     114.11     1004.24      28.10      93.     4.06    157.9
  2.98     144.68     1000.76      27.77      94.     4.21    150.6
  3.31     171.82      997.68      27.59      94.     4.33    156.3
  3.64     199.26      994.57      27.19      94.     4.24    161.0
  3.97     225.53      991.60      26.96      95.     4.12    155.1
  4.30     252.40      988.57      26.74      95.     4.35    157.4
  4.64     272.03      986.36      26.53      95.     4.05    156.5
  4.97     289.20      984.43      26.38      95.     4.35    160.1
  5.30     304.61      982.70      26.18      95.     4.28    164.1
  5.63     319.95      980.98      26.04      95.     4.57    165.9
  5.96     335.31      979.26      25.89      95.     4.40    161.7
  6.29     349.80      977.64      25.72      96.     4.22    162.6
  6.63     365.01      975.94      25.58      96.     4.33    164.1
  6.96     379.72      974.30      25.52      96.     4.77    168.1
  7.29     391.38      973.00      25.32      96.     4.78    163.0
  7.62     402.43      971.77      25.18      96.     4.78    164.0
  7.95     411.06      970.81      25.15      96.     4.60    164.7
  8.29     419.87      969.83      25.00      96.     4.66    162.5
  8.62     431.30      968.56      24.95      96.     4.55    161.2
  8.95     437.07      967.92      24.92      96.     4.79    157.0
  9.28     437.70      967.85      24.91      96.     5.24    156.9
  9.61     436.89      967.94      24.94      96.     5.13    167.9
  9.95     436.35      968.00      24.84      96.     5.33    161.2
 10.28     421.67      969.63      24.85      96.     6.16    161.5
 10.61     405.58      971.42      25.00      96.     7.00    161.9
 10.94     387.98      973.38      25.22      96.     6.95    161.4
 11.27     369.69      975.42      25.32      96.     6.08    158.6
 11.60     349.55      977.67      25.46      96.     6.28    168.2
 11.94     329.53      979.91      25.63      96.     6.56    156.9
 12.27     308.66      982.25      25.90      95.     6.32    154.2
 12.60     285.77      984.82      26.06      95.     6.08    156.3
 12.93     260.72      987.64      26.23      95.     6.06    152.1
 13.26     237.13      990.30      26.47      95.     5.83    162.2
 13.60     210.58      993.30      26.72      95.     5.69    156.2
```

File 9   Tethersonde data

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HAA 780923 506    P1 .0000E  0 .0000E  0 .4000E  1 .6066E  7 .1081E  8 .6034E  7
HAA 780923 506    P2 .3444E  7 .2096E  7 .1259E  7 .6236E  6 .1650E  6 .4196E  5
HAA 780923 506    P3 .2137E  5 .9943E  4 .4239E  4 .1391E  4 .4330E  3 .1130E  3
HAA 780923 506    P4 .3200E  2 .6250E  2 .1000E  1
HAA 780923 508    P1 .0000E  0 .0000E  0 .0000E  0 .1972E  6 .3336E  6 .1893E  6
HAA 780923 508    P2 .1109E  6 .7002E  5 .4377E  5 .2268E  5 .6378E  4 .1517E  4
HAA 780923 508    P3 .7010E  3 .3410E  3 .1250E  3 .5300E  2 .8000E  1 .3000E  1
HAA 780923 508    P4 .0000E  0 .2000E  1 .1000E  1
HAA 780923 510    P1 .0000E  0 .0000E  0 .0000E  0 .1987E  6 .3315E  6 .1884E  6
HAA 780923 510    P2 .1114E  6 .7024E  5 .4387E  5 .2353E  5 .6616E  4 .1480E  4
HAA 780923 510    P3 .7040E  3 .3550E  3 .1330E  3 .5300E  2 .7000E  1 .8000E  1
HAA 780923 510    P4 .1000E  1 .2000E  1 .1000E  1
HAA 780923 512    P1 .0000E  0 .0000E  0 .0000E  0 .1992E  6 .3318E  6 .1890E  6
HAA 780923 512    P2 .1100E  6 .7008E  5 .4342E  5 .2319E  5 .6447E  4 .1481E  4
HAA 780923 512    P3 .7560E  3 .3620E  3 .1660E  3 .4600E  2 .1700E  2 .2000E  1
HAA 780923 512    P4 .0000E  0 .2000E  1 .1000E  1
HAA 780923 514    P1 .0000E  0 .0000E  0 .0000E  0 .1998E  6 .3326E  6 .1888E  6
HAA 780923 514    P2 .1107E  6 .7013E  5 .4412E  5 .2350E  5 .6669E  4 .1463E  4
HAA 780923 514    P3 .7270E  3 .3760E  3 .1280E  3 .3700E  2 .1400E  2 .2000E  1
HAA 780923 514    P4 .0000E  0 .2000E  1 .1000E  1
HAA 780923 516    P1 .0000E  0 .0000E  0 .0000E  0 .2009E  6 .3316E  6 .1881E  6
HAA 780923 516    P2 .1105E  6 .7049E  5 .4402E  5 .2325E  5 .6550E  4 .1562E  4
HAA 780923 516    P3 .7470E  3 .3440E  3 .1350E  3 .5400E  2 .6000E  1 .5000E  1
HAA 780923 516    P4 .0000E  0 .2000E  1 .1000E  1
HAA 780923 518    P1 .0000E  0 .0000E  0 .0000E  0 .1996E  6 .3321E  6 .1877E  6
HAA 780923 518    P2 .1111E  6 .7105E  5 .4463E  5 .2383E  5 .6535E  4 .1467E  4
HAA 780923 518    P3 .7370E  3 .3500E  3 .1300E  3 .5500E  2 .1200E  2 .6000E  1
HAA 780923 518    P4 .0000E  0 .2000E  1 .1000E  1
HAA 780923 520    P1 .0000E  0 .0000E  0 .0000E  0 .2007E  6 .3318E  6 .1873E  6
HAA 780923 520    P2 .1104E  6 .7025E  5 .4407E  5 .2312E  5 .6347E  4 .1529E  4
HAA 780923 520    P3 .7190E  3 .3350E  3 .1370E  3 .4800E  2 .1400E  2 .6000E  1
HAA 780923 520    P4 .1000E  1 .2000E  1 .1000E  1
HAA 780923 522    P1 .0000E  0 .0000E  0 .0000E  0 .2016E  6 .3301E  6 .1873E  6
HAA 780923 522    P2 .1098E  6 .6979E  5 .4355E  5 .2295E  5 .6189E  4 .1438E  4
HAA 780923 522    P3 .6400E  3 .3420E  3 .1510E  3 .5400E  2 .1200E  2 .1000E  1
HAA 780923 522    P4 .2000E  1 .2000E  1 .1000E  1
HAA 780923 524    P1 .0000E  0 .0000E  0 .0000E  0 .2015E  6 .3305E  6 .1871E  6
HAA 780923 524    P2 .1098E  6 .6885E  5 .4268E  5 .2225E  5 .6103E  4 .1406E  4
HAA 780923 524    P3 .6780E  3 .3260E  3 .1400E  3 .4700E  2 .2100E  2 .2000E  1
HAA 780923 524    P4 .3000E  1 .2000E  1 .1000E  1
HAA 780923 526    P1 .0000E  0 .0000E  0 .0000E  0 .2014E  6 .3293E  6 .1854E  6
HAA 780923 526    P2 .1087E  6 .6890E  5 .4296E  5 .2250E  5 .6123E  4 .1445E  4
HAA 780923 526    P3 .7140E  3 .3080E  3 .1400E  3 .5400E  2 .1500E  2 .5000E  1
HAA 780923 526    P4 .0000E  0 .2000E  1 .1000E  1
HAA 780923 528    P1 .0000E  0 .0000E  0 .2000E  1 .2040E  6 .3292E  6 .1852E  6
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File 10   AQML OPC raw data

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HAA 7809281514    E     0     1     6     8     6    20    51    60    31    15
HAA 7809281516    E     0     3    14    13     6    20    51    59    31    16
HAA 7809281518    E     1     1     8     8     0    25    51    60    32    16
HAA 7809281520    E     0     4     7     3    10    22    54    59    32    15
HAA 7809281522    E     2     0     5     8     4    21    52    59    32    15
HAA 7809281524    E     1     0     7     8     5    20    52    59    30    16
HAA 7809281526    E     1     1     4     7     5    19    51    59    31    15
HAA 7809281528    E     2     0     5     5     6    19    50    58    31    16
HAA 7809281530    E     0     0     5     6     4    19    51    57    31    15
HAA 7809281532    E     2     1     4     7     4    18    49    58    32    14
HAA 7809281534    E     0     1     5     7     4    18    47    58    31    15
HAA 7809281536    E     0     1     5     5     3    17    49    57    32    14
HAA 7809281538    E     0     1     4     4     4    18    49    57    30    15
HAA 7809281540    E     0     2     3     5     4    18    48    57    31    15
HAA 7809281542    E     0     1     4     4     4    17    48    57    31    14
HAA 7809281544    E     0     1     4     4     4    17    48    57    31    14
HAA 7809281546    E     1     0     3     5     3    17    49    55    31    15
HAA 7809281548    E     0     1     2     6     4    16    48    56    31    15
HAA 7809281550    E     0     0     3     5     3    17    47    57    30    16
HAA 7809281552    E     0     1     2     4     3    17    49    57    30    14
HAA 7809281555    E     0     1     5     4     4    17    46    57    30    15
HAA 7809281557    E     0     1     5     4     4    17    46    57    30    15
HAA 7809281559    E     0     1    10    11     5    18    46    56    31    15
HAA 78[illegible]9281601    E     0     3     6     7     4    16    47    54    30    15
HAA 7809281603    E     3     1     5     7     4    17    45    57    29    16
HAA 7809281605    E     0     3     2     7     4    15    46    55    30    16
HAA 7809281607    E     0     2     2     5     4    18    44    54    31    15
HAA 7809281609    E     1     0     6     6     4    17    46    54    31    15
HAA 7809281611    E     0     1     4     7     4    17    46    55    30    15
HAA 7809281613    E     1     0     6     6     5    18    44    55    30    15
HAA 7809281615    E     1     2     3     7     6    15    46    56    29    14
HAA 7809281617    E     2     0     3     8     5    17    44    56    28    14
HAA 7809281619    E     0     0     3     5     6    15    45    54    30    13
HAA 7809281621    E     0     2     2     7     4    16    45    54    28    15
HAA 7809281623    E     0     0     5     7     5    16    43    54    28    15
HAA 7809281625    E     0     2     3     9     4    17    43    53    29    13
HAA 7809281627    E     0     2     2     9     4    16    43    54    27    14
HAA 7809281629    E     0     2     5     6     5    14    44    51    30    12
HAA 7809281631    E     0     1     3    10     3    15    44    51    28    13
HAA 7809281633    E     1     0     4     8     4    16    43    52    28    13
HAA 7809281635    E     0     0    10     7     5    13    45    51    27    14
HAA 7809281637    E     0     0    10     7     5    13    45    51    27    14
HAA 7809281639    E     2     2     5     5     4    14    43    53    26    14
HAA 7809281641    E     1     2     5     7     3    16    42    51    28    13
HAA 7809281643    E     1     0     5     6     3    15    43    52    27    12
```

File 1 AQML EAA raw data

```
HAA178 9281514    F1 .0000E  0 .3440E  5 .8400E  4 .5728E  4 .2208E  4 .3780E  4
HAA178 9281514    F2 .4957E  4 .2976E  4 .7905E  3 .1965E  3
HAA178 9281514    G1 .0000E  0 .6080E  1 .4680E  1 .1016E  2 .1236E  2 .6680E  2
HAA178 9281514    G2 .2754E  3 .5280E  3 .4433E  3 .3465E  3
HAA178 9281514    H1 .0000E  0 .7600E -2 .1038E -1 .4000E -1 .8700E -1 .8340E  0
HAA178 9281514    H2 .6120E  1 .2076E  2 .3100E  2 .4335E  2
HAA178 9281516    F1 .0000E  0 .1032E  6 .1960E  5 .9308E  4 .2208E  4 .3780E  4
HAA178 9281516    F2 .4957E  4 .2926E  4 .7905E  3 .2096E  3
HAA178 9281516    G1 .0000E  0 .1824E  2 .1092E  2 .1651E  2 .1236E  2 .6680E  2
HAA178 9281516    G2 .2754E  3 .5192E  3 .4433E  3 .3696E  3
HAA178 9281516    H1 .0000E  0 .2280E -1 .2422E -1 .6500E -1 .8700E -1 .8340E  0
HAA178 9281516    H2 .6120E  1 .2041E  2 .3100E  2 .4624E  2
HAA178 9281518    F1 .1300E  7 .3440E  5 .1120E  5 .5728E  4 .0000E  0 .4725E  4
HAA178 9281518    F2 .4957E  4 .2976E  4 .8160E  3 .2096E  3
HAA178 9281518    G1 .7200E  2 .6080E  1 .6240E  1 .1016E  2 .0000E  0 .8350E  2
HAA178 9281518    G2 .2754E  3 .5280E  3 .4576E  3 .3696E  3
HAA178 9281518    H1 .5040E -1 .7600E -2 .1384E -1 .4000E -1 .0000E  0 .1042E  1
HAA178 9281518    H2 .6120E  1 .2076E  2 .3200E  2 .4624E  2
HAA178 9281520    F1 .0000E  0 .1376E  6 .9800E  4 .2148E  4 .3680E  4 .4158E  4
HAA178 9281520    F2 .5249E  4 .2926E  4 .8160E  3 .1965E  3
HAA178 9281520    G1 .0000E  0 .2432E  2 .5460E  1 .3810E  1 .2060E  2 .7348E  2
HAA178 9281520    G2 .2916E  3 .5192E  3 .4576E  3 .3465E  3
HAA178 9281520    H1 .0000E  0 .3040E -1 .1211E -1 .1500E -1 .1450E  0 .9174E  0
HAA178 9281520    H2 .6480E  1 .2041E  2 .3200E  2 .4335E  2
HAA178 9281522    F1 .2600E  7 .0000E  0 .7000E  4 .5728E  4 .1472E  4 .3969E  4
HAA178 9281522    F2 .5054E  4 .2926E  4 .8160E  3 .1965E  3
HAA178 9281522    G1 .1440E  3 .0000E  0 .3900E  1 .1016E  2 .8240E  1 .7014E  2
HAA178 9281522    G2 .2808E  3 .5192E  3 .4576E  3 .3465E  3
HAA178 9281522    H1 .1008E  0 .0000E  0 .8650E -2 .4000E -1 .5800E -1 .8757E  0
HAA178 9281522    H2 .6240E  1 .2041E  2 .3200E  2 .4335E  2
HAA178 9281524    F1 .1300E  7 .0000E  0 .9800E  4 .5728E  4 .1840E  4 .3780E  4
HAA178 9281524    F2 .5054E  4 .2926E  4 .7650E  3 .2096E  3
HAA178 9281524    G1 .7200E  2 .0000E  0 .5460E  1 .1016E  2 .1030E  2 .6680E  2
HAA178 9281524    G2 .2808E  3 .5192E  3 .4290E  3 .3696E  3
HAA178 9281524    H1 .5040E -1 .0000E  0 .1211E -1 .4000E -1 .7250E -1 .8340E  0
HAA178 9281524    H2 .6240E  1 .2041E  2 .3000E  2 .4624E  2
HAA178 9281526    F1 .1300E  7 .3440E  5 .5600E  4 .5012E  4 .1840E  4 .3591E  4
HAA178 9281526    F2 .4957E  4 .2926E  4 .7905E  3 .1965E  3
HAA178 9281526    G1 .7200E  2 .6080E  1 .3120E  1 .8890E  1 .1030E  2 .6346E  2
HAA178 9281526    G2 .2754E  3 .5192E  3 .4433E  3 .3465E  3
HAA178 9281526    H1 .5040E -1 .7600E -2 .6920E -2 .3500E -1 .7250E -1 .7923E  0
HAA178 9281526    H2 .6120E  1 .2041E  2 .3100E  2 .4335E  2
HAA178 9281528    F1 .2600E  7 .0000E  0 .7000E  4 .3580E  4 .2208E  4 .3591E  4
HAA178 9281528    F2 .4860E  4 .2877E  4 .7905E  3 .2096E  3
HAA178 9281528    G1 .1440E  3 .0000E  0 .3900E  1 .6350E  1 .1236E  2 .6346E  2
```

File 12 AOML EAA reduced data

```
HAA 780923 506    Q1 .0000E 00 .0000E 00 .1085E-03 .1645E 03 .2932E 03 .1637E 03
HAA 780923 506    Q2 .9341E 02 .5685E 02 .3415E 02 .1691E 02 .4475E 01 .1138E 01
HAA 780923 506    Q3 .5796E 00 .2697E 00 .1150E 00 .3773E-01 .1174E-01 .3065E-02
HAA 780923 506    Q4 .8679E-03
HAA 780923 506    R1 .0000E 00 .0000E 00 .7343E-04 .1634E 03 .4275E 03 .3503E 03
HAA 780923 506    R2 .2934E 03 .2621E 03 .2311E 03 .1680E 03 .6526E 02 .2436E 02
HAA 780923 506    R3 .1821E 02 .1244E 02 .7781E 01 .3748E 01 .1712E 01 .6560E 00
HAA 780923 506    R4 .2727E 00
HAA 780923 506    S1 .0000E 00 .0000E 00 .5680E-05 .1532E 02 .4855E 02 .4819E 02
HAA 780923 506    S2 .4891E 02 .5293E 02 .5654E 02 .4980E 02 .2343E 02 .1060E 02
HAA 780923 506    S3 .9597E 01 .7940E 01 .6020E 01 .3513E 01 .1944E 01 .9024E 00
HAA 780923 506    S4 .4544E 00
HAA 780923 508    Q1 .0000E 00 .0000E 00 .0000E 00 .1671E 03 .2827E 03 .1604E 03
HAA 780923 508    Q2 .9399E 02 .5935E 02 .3710E 02 .1922E 02 .5406E 01 .1286E 01
HAA 780923 508    Q3 .5941E 00 .2890E 00 .1059E 00 .4492E-01 .6780E-02 .2543E-02
HAA 780923 508    Q4 .0000E 00
HAA 780923 508    R1 .0000E 00 .0000E 00 .0000E 00 .1660E 03 .4123E 03 .3434E 03
HAA 780923 508    R2 .2953E 03 .2737E 03 .2511E 03 .1910E 03 .7883E 02 .2752E 02
HAA 780923 508    R3 .1867E 02 .1333E 02 .7171E 01 .4463E 01 .9887E 00 .5442E 00
HAA 780923 508    R4 .0000E 00
HAA 780923 508    S1 .0000E 00 .0000E 00 .0000E 00 .1556E 02 .4682E 02 .4724E 02
HAA 780923 508    S2 .4922E 02 .5526E 02 .6142E 02 .5660E 02 .2830E 02 .1197E 02
HAA 780923 508    S3 .9837E 01 .8510E 01 .5547E 01 .4183E 01 .1123E 01 .7487E 00
HAA 780923 508    S4 .0000E 00
HAA 780923 510    Q1 .0000E 00 .0000E 00 .0000E 00 .1684E 03 .2810E 03 .1597E 03
HAA 780923 510    Q2 .9442E 02 .5953E 02 .3718E 02 .1994E 02 .5607E 01 .1254E 01
HAA 780923 510    Q3 .5967E 00 .3009E 00 .1127E 00 .4492E-01 .5933E-02 .6780E-02
HAA 780923 510    Q4 .8475E-03
HAA 780923 510    R1 .0000E 00 .0000E 00 .0000E 00 .1673E 03 .4097E 03 .3418E 03
HAA 780923 510    R2 .2966E 03 .2745E 03 .2517E 03 .1981E 03 .8177E 02 .2685E 02
HAA 780923 510    R3 .1875E 02 .1387E 02 .7630E 01 .4463E 01 .8651E 00 .1451E 01
HAA 780923 510    R4 .2663E 00
HAA 780923 510    S1 .0000E 00 .0000E 00 .0000E 00 .1568E 02 .4652E 02 .4702E 02
HAA 780923 510    S2 .4944E 02 .5543E 02 .6157E 02 .5872E 02 .2936E 02 .1168E 02
HAA 780923 510    S3 .9880E 01 .8859E 01 .5902E 01 .4183E 01 .9823E 00 .1996E 01
HAA 780923 510    S4 .4438E 00
HAA 780923 512    Q1 .0000E 00 .0000E 00 .0000E 00 .1688E 03 .2812E 03 .1602E 03
HAA 780923 512    Q2 .9323E 02 .5940E 02 .3680E 02 .1965E 02 .5464E 01 .1255E 01
HAA 780923 512    Q3 .6407E 00 .3068E 00 .1407E 00 .3899E-01 .1441E-01 .1695E-02
HAA 780923 512    Q4 .0000E 00
HAA 780923 512    R1 .0000E 00 .0000E 00 .0000E 00 .1677E 03 .4101E 03 .3429E 03
HAA 780923 512    R2 .2929E 03 .2739E 03 .2491E 03 .1953E 03 .7968E 02 .2687E 02
HAA 780923 512    R3 .2013E 02 .1415E 02 .9523E 01 .3873E 01 .2101E 01 .3628E 00
HAA 780923 512    R4 .0000E 00
HAA 780923 512    S1 .0000E 00 .0000E 00 .0000E 00 .1572E 02 .4656E 02 .4717E 02
```

File 13   AQML OPC reduced data

```
T0287909150730   86   79   0   3  109   76   74   76    4      119   0    6
T0287909150735  113  105   0   3  120   76   73   76    5      119   0    2
T0287909150740  123  120   0   3  129   76   73   76    8      120   0    5
T0287909150745  111  103   0   3  124   77   74   76   10      119   0   11
T0287909150750  130  121   0   3  122   77   73   76   11      119   0    0
T0287909150755  104   97   0   3  120   77   73   76   13      119   0    8
T0287909150800   91   84   0   4  123   77   73   76   15      118   0    5
T0287909150805   88   79   0   3  123   77   72   78   18      118   0   11
T0287909150810   85   78   0   3  126   77   73   78   20      120   0    5
T0287909150815   75   67   0   4  122   77   74   78   22      119   0   11
T0287909150820   73   64   0   4  117   78   73   78   26      118   0   13
T0287909150825   63   56   0   5  130   78   72   78   27      118   0    8
T0287909150830   56   48   0   5  128   78   73   79   26      119   0   10
T0287909150835   50   41   0   5  134   78   73   79   32      117   0    7
T0287909150840   46   37   0   5  138   78   72   79   30      117   0   12
T0287909150845   41   32   0   6  133   78   73   80   35      120   0    6
T0287909150850   33   25   0   7  141   78   73   80   38      119   0   12
T0287909150855   30   21   0   6  145   78   72   80   42      118   0   16
T0287909150900   29   20   0   6  142   79   73   81   38      120   0   10
T0287909150905   27   19   0   5  146   78   73   81   44      118   0    9
T0287909150910   20   13   0   7  154   78   72   81   49      118   0   10
T0287909150915   18   11   0   6  163   78   72   83   43      119   0   12
T0287909150920   19   11   0   6  170   78   73   83   53      118   1   11
T0287909150925   15    9   0   7  156   78   72   83   63      118   1    9
T0287909150930   14    9   0   6  169   78   72   84   71      119   2    9
T0287909150935   13    9   0   6  180   78   73   84   74      119   2   14
T0287909150940   12    8   0   6  172   78   72   85   56      118   3   15
T0287909150945   10    5   0   7  166   77   72   84   64      118   4    5
T0287909150950    8    5   0   7  172   77   72   84   62      119   4   10
T0287909150955   10    5   0   8  172   77   73   84   43      118   4   14
T0287909151000   11    5   0   8  170   76   72   84   26      118   3    9
T0287909151005   17    9   0   7  178   76   71   84   31      118   2    7
T0287909151010   17   11   0   6  188   77   73   84   82      119   4   18
T0287909151015    7    4   0   8  163   75   75   85   64      119   6    5
T0287909151020   10    6   0   7  161   76   75   85   73      118   4   15
T0287909151025   11    6   0   6  165   76   74   85   90      118   5   18
T0287909151030   12    7   0   7  152   76   75   85   92      120   5    7
T0287909151035   14    9   0   7  168   76   75   85   98      118   4   11
T0287909151040   13    8   0   6  176   76   74   86   98      118   4   14
T0287909151045   11    6   0   8  166   75   75   86   90      119   6    8
T0287909151050    8    4   0   6  170   75   75   86   93      118   7   15
T0287909151055    8    5   0   4  181   75   74   86  108      118   8   12
T0287909151100    8    4   0   6  141   75   75   88  110      119   9   16
T0287909151105    8    4   0   6  161   75   76   88   78      117   9   15
T0287909151110   10    5   0   6  163   75   75   88   98      117   9   14
```

File 14   Trailer 28 continuous data, September

T0287910010000	148	108	0	0	342	65	73	73	0	0	118	1	6
T0287910010005	169	128	0	0	262	65	75	73	0	0	118	1	21
T0287910010010	178	141	0	0	250	65	74	73	0	0	118	1	11
T0287910010015	155	116	0	0	272	66	74	73	0	0	118	1	0
T0287910010020	155	117	0	0	336	66	75	73	0	0	118	1	15
T0287910010025	189	150	0	1	326	66	73	73	0	0	118	1	14
T0287910010030	196	160	0	1	346	66	74	71	0	0	119	1	12
T0287910010035	202	165	0	0	4	66	74	71	0	0	118	1	0
T0287910010040	197	164	0	0	1	66	73	71	0	0	118	1	2
T0287910010045	198	164	0	0	244	66	74	70	0	0	119	1	
T0287910010050	192	158	0	0	198	66	74	71	0	0	118	1	2
T0287910010055	203	169	0	0	247	66	73	71	0	0	119	1	0
T0287910010100	187	151	0	0	292	66	74	71	0	0	118	1	7
T0287910010105	207	174	0	1	291	66	74	71	0	0	118	1	4
T0287910010110	216	183	0	0	279	66	74	71	0	0	119	1	9
T0287910010115	214	182	0	0	310	66	74	70	0	0	118	1	0
T0287910010120	222	191	0	0	310	66	73	70	0	0	118	1	22
T0287910010125	218	190	0	0	267	66	74	70	0	0	119	1	7
T0287910010130	213	183	0	0	310	66	74	70	0	0	118	1	13
T0287910010135	209	179	0	0	298	66	73	70	0	0	119	1	7
T0287910010140	221	189	0	1	307	66	74	70	0	0	119	1	15
T0287910010145	235	209	0	0	285	66	74	70	0	0	118	1	14
T0287910010150	220	190	0	0	267	66	73	70	0	0	119	1	14
T0287910010155	211	181	0	0	278	66	74	70	0	0	119	1	14
T0287910010200	208	179	0	0	334	66	73	70	0	0	118	1	9
T0287910010205	210	181	0	0	308	66	74	70	0	0	119	1	28
T0287910010210	221	192	0	0	279	66	75	70	0	0	118	1	11
T0287910010215	212	183	0	0	274	66	73	69	0	0	118	1	13
T0287910010220	215	184	0	0	299	66	74	69	0	0	118	1	14
T0287910010225	237	205	0	0	307	66	74	70	0	0	118	1	17
T0287910010230	205	181	0	0	294	66	73	70	0	0	118	1	0
T0287910010235	205	177	0	0	289	66	74	69	0	0	118	1	13
T0287910010240	237	209	0	0	314	66	74	69	0	0	118	1	10
T0287910010245	226	199	0	1	321	66	73	69	0	0	118	1	14
T0287910010250	224	198	0	0	309	66	74	69	0	0	119	1	0
T0287910010255	234	206	0	0	321	66	74	69	0	0	118	1	7
T0287910010300	248	223	0	1	341	66	73	69	0	0	118	1	3
T0287910010305	236	211	0	0	322	66	74	69	0	0	118	1	11
T0287910010310	236	210	0	0	328	66	74	69	0	0	118	1	14
T0287910010315	243	217	0	1	334	66	73	69	0	0	119	1	14
T0287910010320	232	207	0	0	322	66	74	69	0	0	119	1	0
T0287910010325	232	208	0	0	323	66	73	68	0	0	118	1	12
T0287910010330	234	209	0	0	334	65	73	68	0	0	119	1	10
T0287910010335	234	208	0	1	342	66	74	68	0	0	119	1	15
T0287910010340	233	207	0	1	346	65	73	68	0	0	118	1	0

File 15   Trailer 28 continuous data, October

```
T0997809230345
T0997809230350
T0997809230355
T0997809230400
T0997809230405
T0997809230410
T0997809230415
T0997809230420
T0997809230425
T0997809230430
T0997809230435
T0997809230440
T0997809230445
T0997809230450
T0997809230455
T0997809230500               28  21   0  19  322
T0997809230505               28  21   0  19  322
T0997809230510               28  21   0  19  322
T0997809230515               28  21   0  19  322
T0997809230520               28  21   0  19  322
T0997809230525               28  21   0  19  322
T0997809230530               28  21   0  19  322
T0997809230535               28  21   0  19  322
T0997809230540               28  21   0  19  322
T0997809230545               28  21   0  19  322
T0997809230550               28  21   0  19  322
T0997809230555               28  21   0  19  322
T0997809230600               28  21   0  19  322
T0997809230605               28  21   0  19  322
T0997809230610               31   2   0       315
T0997809230615               31   2   0       313
T0997809230620               31   1   0       311
T0997809230625               30   1   0       313
T0997809230630               29       0       313
T0997809230635               28   2   0       313
T0997809230640               28   1   0       315
T0997809230645               28   2   0       314
T0997809230650               27   1   0       315
T0997809230655               28   2   0       313
T0997809230700   3   2       29   2   0   0  312
T0997809230705   5   2       27   3   0   0  312
T0997809230710   3   1       27   1   0   0  311
T0997809230715   3   1       26   2   0   0  310
T0997809230720   2   0       25   1   0   0  310
T0997809230725   2   0       27   2   0   0  309
```

File 16   AQML continuous data, September

```
T0997810020600  192  160    0         32         1  333
T0997810020605  227  195    2    0    32         2  333
T0997810020610  233  207    0    0    26         1  333
T0997810020615  231  195         0    36         1  333
T0997810020620  239  211    1    0    28         1  333
T0997810020625  292  259              33         2  333
T0997810020630  349  312    0    0    37         3  333
T0997810020635  355  319    0    0    37         3  333
T0997810020640  360  319         0    41         3  333
T0997810020645  360  319         0    41         3  333
T0997810020650  386  344    1    0    41         4  333
T0997810020655  394  357    0    0    37         4  333
T0997810020700  410  371    2    0    38    0    5  333
T0997810020705  379  343    1    0    35    0    4  333
T0997810020710
T0997810020715
T0997810020720
T0997810020725
T0997810020730  385  339         0    46    6    5  333
T0997810020735  395  355    1         40    6    7  333
T0997810020740  374  337    0         36    2    7  333
T0997810020745  403  367    1    0    36    2    6  333
T0997810020750  358  315    0    0    43    1    5  333
T0997810020755  372  332         0    40         6  333
T0997810020800  347  308         0    39    0    5  333
T0997810020805  395  345    2    0    50    0    6  333
T0997810020810  339  295         0    43    0    5  333
T0997810020815  269  221    2    0    49    0    3  333
T0997810020820  223  176    0    0    47    0    2  333
T0997810020825  223  173    1    0    49    0    3  333
T0997810020830  226  177    1    0    49    0    2  333
T0997810020835  199  148    0    1    52    0    2  333
T0997810020840  179  124    1    1    55    0    1  333
T0997810020845  147   97    1    3    50    0    1  333
T0997810020850  162  107    2    2    55    0    1  333
T0997810020855  160  112    0    2    48    0    1  333
T0997810020900  152  101    0    2    51    0    1  333
T0997810020905  140   88    2    5    52    0    1  333
T0997810020910  133   75    3    6    59    0    0  333
T0997810020915  123   68    6   10    55    1    0  333
T0997810020920  107   51    9   11    55    7    0  333
T0997810020925  113   57    9   11    56    7    0  333
T0997810020930  119   62    8   11    57   10    0  333
T0997810020935  133   63    6    9    70    8    0  333
T0997810020940  154   71    7   11    82   13    0  333
```

File 17   AQML continuous data, October